10. 40 CFR 122.21(R)(10) - COMPREHENSIVE TECHNICAL FEASIBILITY AND COST EVALUATION STUDY

This report was prepared by Wood Environment & Infrastructure Solutions, Inc.

10.1. INTRODUCTION

In accordance with Section 316(b) of the Clean Water Act, the USEPA has promulgated rules under 40 CFR Part 125, Subpart J (the Rule) that require the determination of BTA to reduce mortality associated with the impingement and entrainment of aquatic biota. At the time a facility submits its NPDES permit application, Section 122.21 (r)(10) of the Rule requires the owner or operator of a facility with a CWIS with flow rates greater than 125 MGD to provide engineering feasibility studies and cost for control technologies and operational measures to minimize entrainment. This Comprehensive Technical Feasibility and Cost Evaluation study is meant to support the determination of site-specific BTA for entrainment.

Under 40 CFR §122.21(r)(10), specific information that must be submitted for the facility includes the technical feasibility of the following alternatives:

- Closed-cycle cooling.
- Fine mesh screens with a mesh size of 2.0 mm or smaller.
- Reuse of water or alternative sources of cooling water.
- An evaluation of any other technologies for reducing entrainment as identified by the applicant or requested by the Director of the USEPA.

The study shall include the following for each entrainment control technology:

- A description of all technologies and operational measures considered (including alternative designs of closed-cycle recirculating systems such as natural draft cooling towers, mechanical draft cooling towers, hybrid designs, and compact or multi-cell arrangements).
- A discussion of land availability, including an evaluation of adjacent land and acres potentially available due to generating unit retirements, production unit retirements, other buildings and equipment retirements, and potential for repurposing of areas devoted to ponds, coal piles, rail yards, transmission yards, and parking lots.
- A discussion of available sources of process water, grey water, waste-water, reclaimed water, or other waters of appropriate quantity and quality for use as some or all of the cooling water needs of the facility.
- Documentation of factors other than cost that may make a candidate technology impractical or infeasible for further evaluation.

Per 40 CFR §122.21(r)(10), facility costs must be adjusted to estimate social costs. Costs must be presented as the NPV and the corresponding annual value, and costs must be clearly labeled as compliance costs or social costs. The applicant must separately discuss facility level compliance costs and social costs, and provide documentation as follows:

- Compliance costs are calculated as after-tax, while social costs are calculated as pre-tax. Compliance costs include the facility's administrative costs, including costs of permit application, while the social cost adjustment includes the Director's administrative costs. Any outages, downtime, or other impacts to facility net revenue are included in compliance costs, while only that portion of lost net revenue that does not accrue to other producers can be included in social costs. Social costs must also be discounted using social discount rates of 3 percent and 7 percent. Assumptions regarding depreciation schedules, tax rates, interest rates, discount rates and related assumptions must be identified.
- Costs and explanation of any additional facility modifications necessary to support construction and operation of technologies considered including, but not limited to, relocation of existing buildings or equipment, reinforcement or upgrading of existing equipment, and additional construction and operating permits. Assumptions regarding depreciation schedules, interest rates, discount rates, useful life of the technology considered, and any related assumptions must be identified.
- Costs and explanation for addressing any non-water quality environmental and other impacts. The cost evaluation must include a discussion of all reasonable attempts to mitigate each of these impacts.

The Rule requires evaluation of a range of technological and operational measures aimed at reducing entrainment losses. For some technologies Wood has performed the evaluation and provides a determination regarding feasibility, practicality and cost. For other technology alternatives (e.g., closed-cycle cooling), Ameren has provided studies, performed by other consultants, that provide the evaluation of the technology and make a determination regarding feasibility, practicality and cost. In all cases the source of the information is identified. This study summarizes the findings of all technologies and operational measures considered, including those specifically required by the Rule. A determination of feasibility for each technology alternative includes evaluation at multiple levels:

- Engineering analysis: technical considerations of interference and impact on existing plant systems, structural considerations, and hydrologic considerations.
- Practicality/Reasonableness: documented effectiveness of the technology, land availability (ownership/zoning), potential impact on waters of the U.S., logistics of implementation, operation and maintenance, ability to meet generation demand, cost, etc.

An alternative that does not meet all of these objectives is infeasible. For the purpose of this report the feasibility of an alternative is the determination by which an alternative will, or will not, be given further consideration and retained for study in 40 CFR §122.21 (r)(11) and (r)(12)

10.2. LABADIE ENERGY CENTER

The LEC is located on the south bank (right descending) of the Missouri River, approximately 35 miles west of St. Louis in Labadie, MO, at river mile 57.5 (Figure 10.1).

The LEC operates year-round as a baseload facility. The plant consists of four generating units with a gross generating capability of 2,580 MW. Over the five-year period of 2014-2018, the average capacity factor for the four units combined was 73.9%, with capacity factors of the individual units ranging from 77.0% to 66.2%. Operation of the plant with respect to Section §316(b) is subject to the conditions of NPDES Permit No. MO-0004812 issued by the Missouri Department of Natural Resources.

10.2.1 Hydraulic Parameters

Water level elevations at the intake typically range from 450.0 ft. at DLWL to 484.0 ft. at high water, but they have reached a maximum level of 490.0 ft. and a minimum low level of 446.0 ft. The MWL is 455.0 ft (Alden 2005).

10.2.2 Circulating Pump Flow Rate Analysis

The LEC's circulating water pumps are vertical pumps installed in a wet pit intake structure. The flow rate provided by the constant speed pumps is dependent on river level. An increase in river elevation reduces pumping head required and increases the pump flow rate. The cooling water system (CWS) of the entire plant is designed for a flow rate of 2,240 cfs at MWL of 455.0 ft. This corresponds to approximately 1,005,400 gpm or 125,700 gpm per pump. At the DLWL of 450.0 ft. the total design flow is 2,104 cfs. This corresponds to 944,300 gpm or 118,000 gpm per pump.

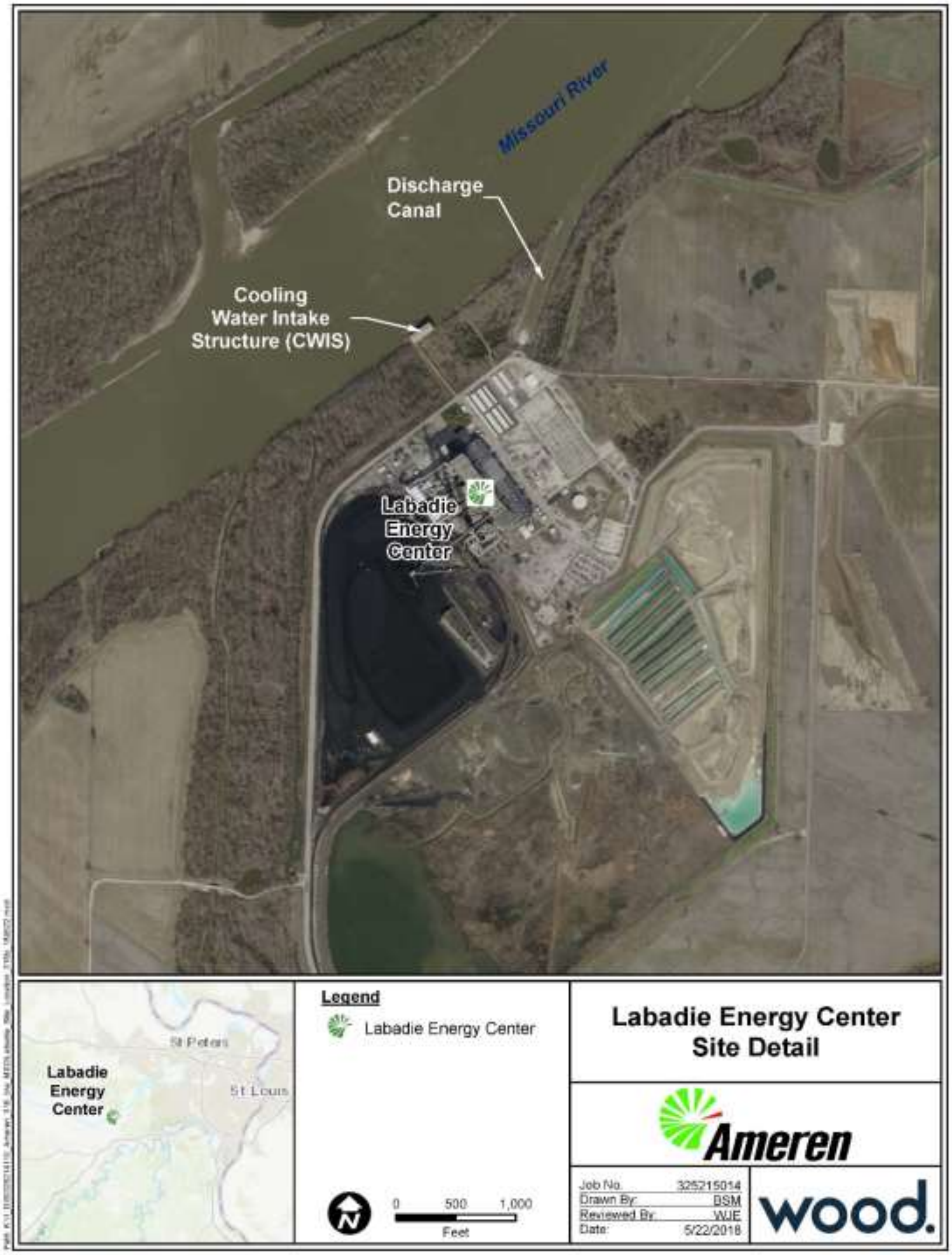


Figure 10.1. Labadie Energy Center Project Location

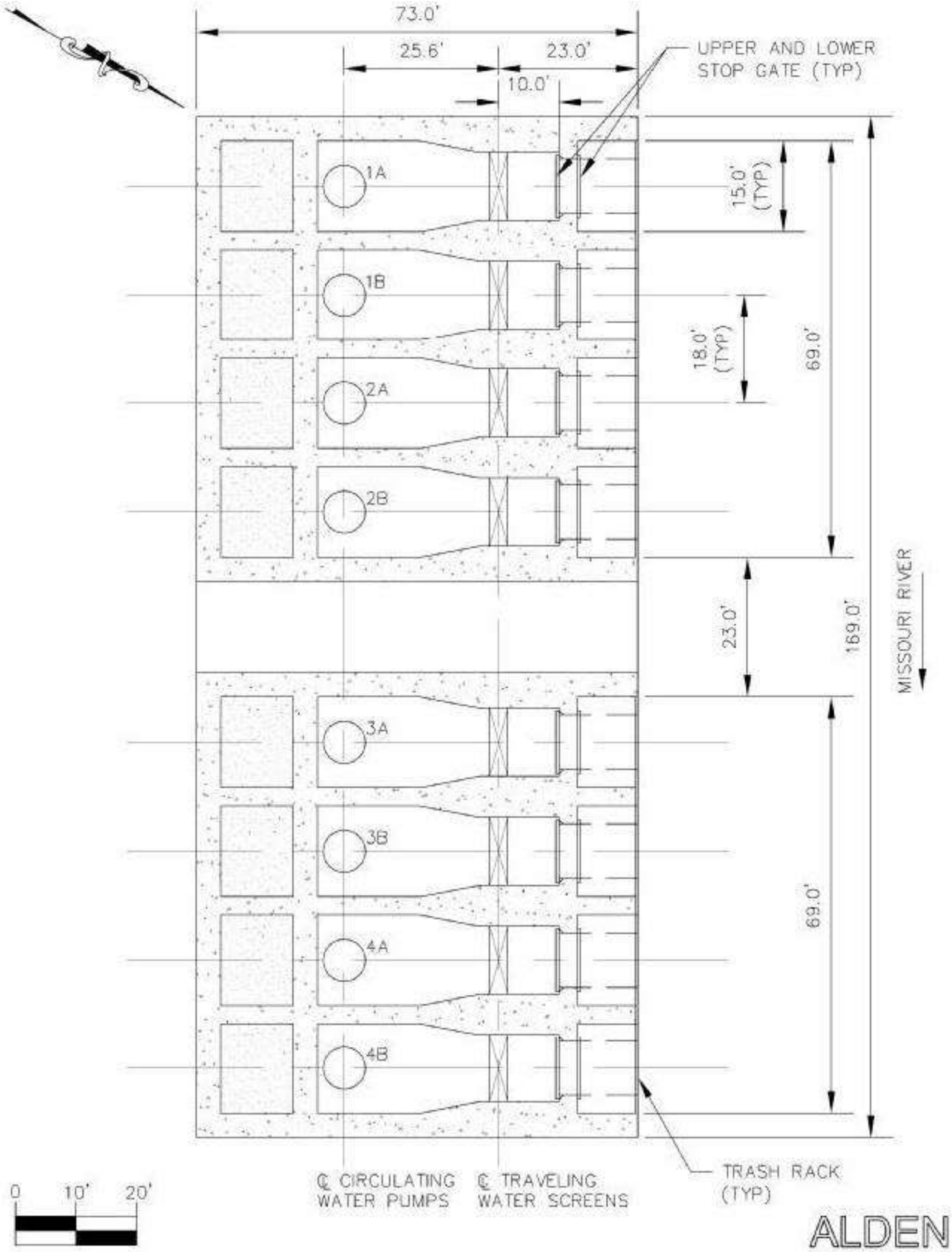
10.2.3 Cooling Water Intake Structure

The LEC’s single shoreline CWIS provides cooling water for all four units. The main channel and greatest depth of the river occur immediately offshore from the intake structure. The CWIS has eight intake bays, two for each unit. Each unit withdraws circulating water through two separate pump bays. Each of the eight bays is about 11 feet wide and has an upper and lower intake opening. Each is equipped with a trash rack, a TWS, and a vertical circulating water pump. Upper and lower intake openings are equipped with full-face exterior bar racks and have separate stop gates and a raking system to remove large debris. During winter months LEC has the ability to direct warm, post-condenser water back to the river side of the stop gates via a recirculation piping system to reduce icing effects. Figures 10.2 and 10.3 provide a schematic plan and section of the CWIS, respectively.

Key intake structure elevations are provided in Table 10.1. For purposes of estimating the through-screen velocity, Table 10.2 summarizes the wetted dimensions of each TWS at design DLWL and MWL.

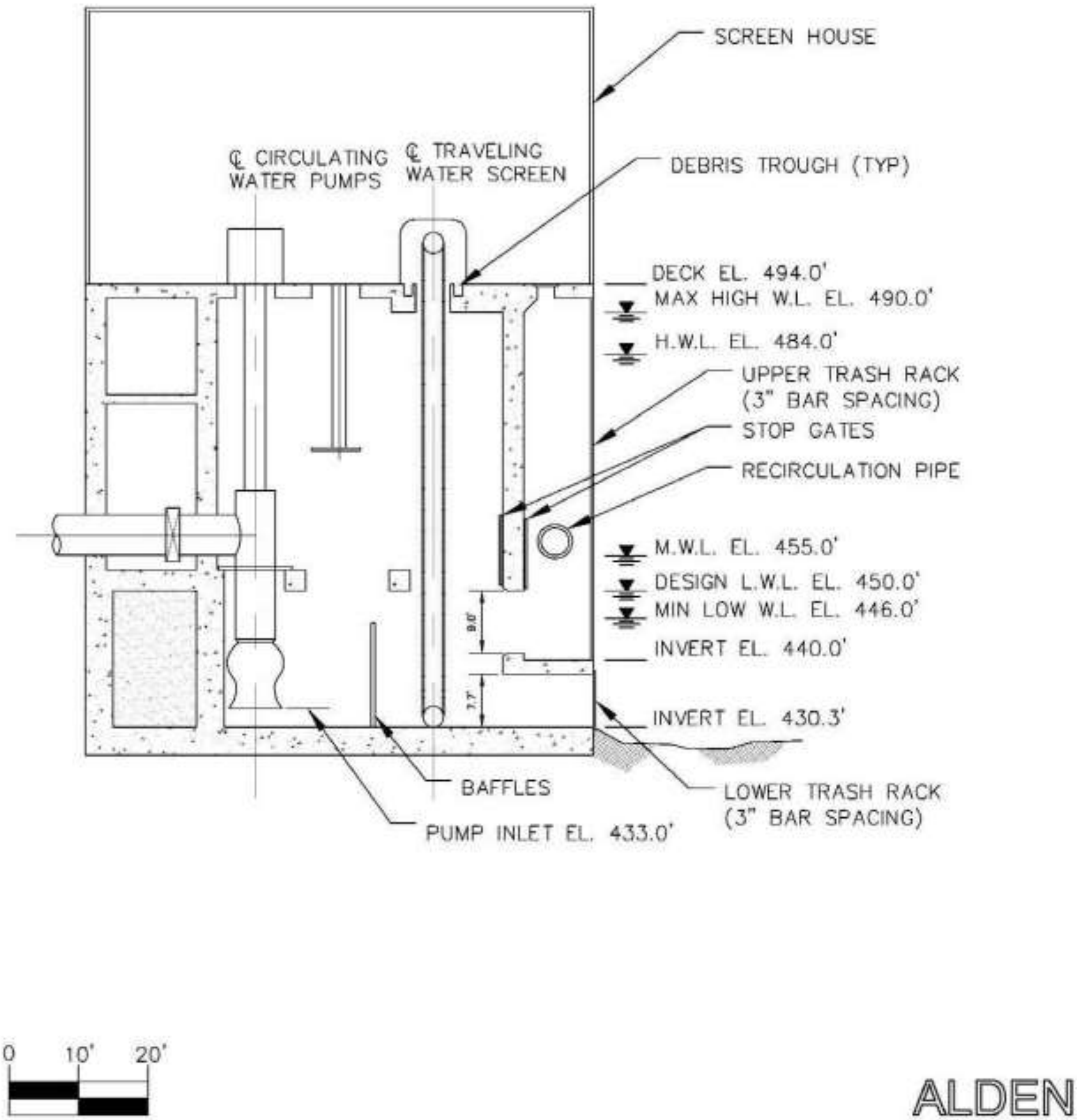
10.2.4 Existing Traveling Water Screens

The current TWSs are comprised of 3/8-inch mesh screen panels. The mesh is estimated to have an open area of approximately 68% when free of debris. The through-screen velocities, presented in Table 10.3, are idealized values based on one-dimensional flow rate calculations assuming clean screens. The screens currently function in a capacity that would be described as a “debris screen” where the screens are rotated periodically on a consistent schedule (e.g., once per shift or once daily) or as head loss develops to ensure spray cleaning with a high-pressure spray system. Organisms and debris sprayed off the screens are returned to the river via the debris trough. Under current operations, the system is not optimized for the protection of impinged fish.



Source: Alden 2005

Figure 10.2. CWIS Plan Detail



Source: Alden 2005

Figure 10.3. CWIS Typical Section

Table 10.1. CWIS Key Elevations

CWIS Feature	Elevation (ft.)
Invert Elevation	430.3
Pump Inlet	433
Required Submergence	12
Historic Min level	445
Historic Low Water Level	446
DLWL	450
MWL	455

Table 10.2. CWIS Screen Bay Dimensions

	River Elevation (ft.)	Width (ft.)	Water Column Height (ft.)	Gross Area (ft^2)
DLWL	450	10	19.7	197
MWL	455	10	24.7	247

Table 10.3. CWIS Existing Through Screen Velocities

	CWIS Flow (cfs)	Flow Per Screen (cfs)	Per Screen Gross Area (ft^2)	Open Area	Thru-Screen Velocity (fps)
MWL	2240	280	247	68%	1.67
DLWL	2104	263	197	68%	1.96

10.3. EVALUATION OF CLOSED-CYCLE COOLING

The §122.21(r)(10) Comprehensive Technical Feasibility and Cost Evaluation Study requires that the technical feasibility and incremental cost of various entrainment control technologies be evaluated, including closed-cycle cooling. Closed-cycle cooling technologies typically represent the greatest potential to significantly reduce entrainment losses because source waterbody withdrawal rates are significantly reduced or eliminated. However, the cost for construction of closed-cycle cooling is typically an order of magnitude greater than other potential entrainment reduction technologies. This is particularly true for large scale baseload plants such as LEC.

As part of on-going facility compliance investigations at LEC external to §316(b), Ameren retained Burns & McDonnell (B&M) to perform a technical and cost feasibility analysis of several thermal reduction technologies that also included closed-cycle cooling alternatives. As reported in "*Ameren Labadie Energy Center Thermal Discharge Best Available Technology Economically Achievable Analysis*" (B&M 2018), B&M initially performed a screening level analysis of closed-cycle cooling alternatives to eliminate non-feasible technologies. More detailed analysis and cost estimates were developed for technologies that were determined to be feasible at LEC. Because the B&M study closely aligns with the request for closed-cycle alternatives referenced in the Rule (r)(10), it provides the sole basis of the feasibility analysis for closed cycle cooling alternatives presented in this study. The following sections concisely summarize the feasibility of closed-cycle alternatives at LEC. The costs developed by B&M (B&M 2018) are included in Appendix 10B of this study. Readers of this study are encouraged to review B&M 2018 in its entirety.

In addition to B&M 2018, Ameren also provided the "*Assessment of Alternative Cooling Technologies for Potential Retrofitting at the Labadie Energy Center*" (Burns 2018), which is provided as an independent review of the B&M 2018 study. Burns 2018 is included in this study as Appendix 10C.

10.3.1 Closed-Cycle Cooling Pond

In total, Ameren owns more than 2,400 acres at LEC. However, lands that have been previously committed, are currently committed, or are planned for committed uses are not suitable for conversion to a cooling pond. Areas such as landfills, ash ponds, or coal storage piles are committed lands and are not available for development as a cooling pond. There are approximately 600 acres within Ameren property limits currently suitable for conversion to a cooling pond. Because of the limitation in existing land availability, the prior analyses (B&M 2018) were limited to partial thermal relief for a single operating unit and did not encompass a fully closed-cycle system.

The heat rejection assumption for sizing a cooling pond at LEC is one acre per MW of cooling duty based on the cooling water heat load and regional atmospheric conditions (B&M 2018). The prior study concluded that 600 acres was sufficient to cool approximately 65% of the heat load from a single generating unit (B&M 2018). By extrapolating these values, a pond with 3,800 acres of surface water would be required to provide full closed-cycle cooling capacity at LEC. Actual implementation of a cooling pond would require additional acreage for berms, dikes, flow control structures, access roads and other support infrastructure. For the purpose of this study an additional 10% of land area is assumed to be required to account for these additional features. Accordingly, the total area required for a closed cycle cooling pond is approximately 4,200 acres.

The Rule requires consideration of adjacent land for conversion to closed-cycle cooling. The land surrounding LEC is primarily low-lying floodplain area. The lands consist of predominantly agricultural uses that are interspersed with wetlands, woody areas and drainage ditches. Several local access roads are present. Other than isolated agricultural support buildings, there are no major industrial, commercial or residential developments in the lands surrounding LEC. Figure 10.4 depicts the configuration of lands potentially available for development of a cooling pond. Including the land already owned by LEC, the total acreage is approximately 3,800 acres, which is divided into two separate tracts that are located east and west of LEC. This land area is likely insufficient to support the full development requirements of a 4,200-acre closed-cycle cooling pond for LEC. Additionally, the arrangement of these lands into two disjunct tracts that are separated by the LEC complex, access roads and Labadie Creek further contribute to the infeasibility of this option.

Permitting of such a large cooling pond arrangement would also be problematic. Lands within the floodplain contain an array of resources that would require permitting including, but not limited to, the following:

- Streams and wetlands (Clean Water Act Section 401 and 404)
- Archaeological resources (National Historic Preservation Act, Section 106)
- Endangered species (Endangered Species Act)

Notably, excluding LEC, all of the land up to the natural bluff boundary on the south side of the bottoms is mapped as regulatory floodway per the FEMA Floodplain Insurance Rate Map (FIRM) (Figure 10.4). Development within the floodway is highly restrictive whereby any planned development would have to demonstrate a “no rise” effect on base flood levels. Development of a large cooling pond would encroach upon the floodway by the construction of large berms that provide protection of the cooling pond from flooding (presumably, the base, 100-year flood). As such, the entirety of the land area dedicated to cooling ponds would have to be removed from the floodway. While smaller floodway encroachments (e.g., piers of a bridge) may be allowable, such a large floodway encroachment is not considered permittable. In consideration of the complexity of environmental permitting, potentially greater effects on streams and wetlands (and other environmental resources) and the inability to permit encroachment in the floodway, the closed-cycle cooling pond alternative is considered infeasible and impractical and is eliminated from consideration.

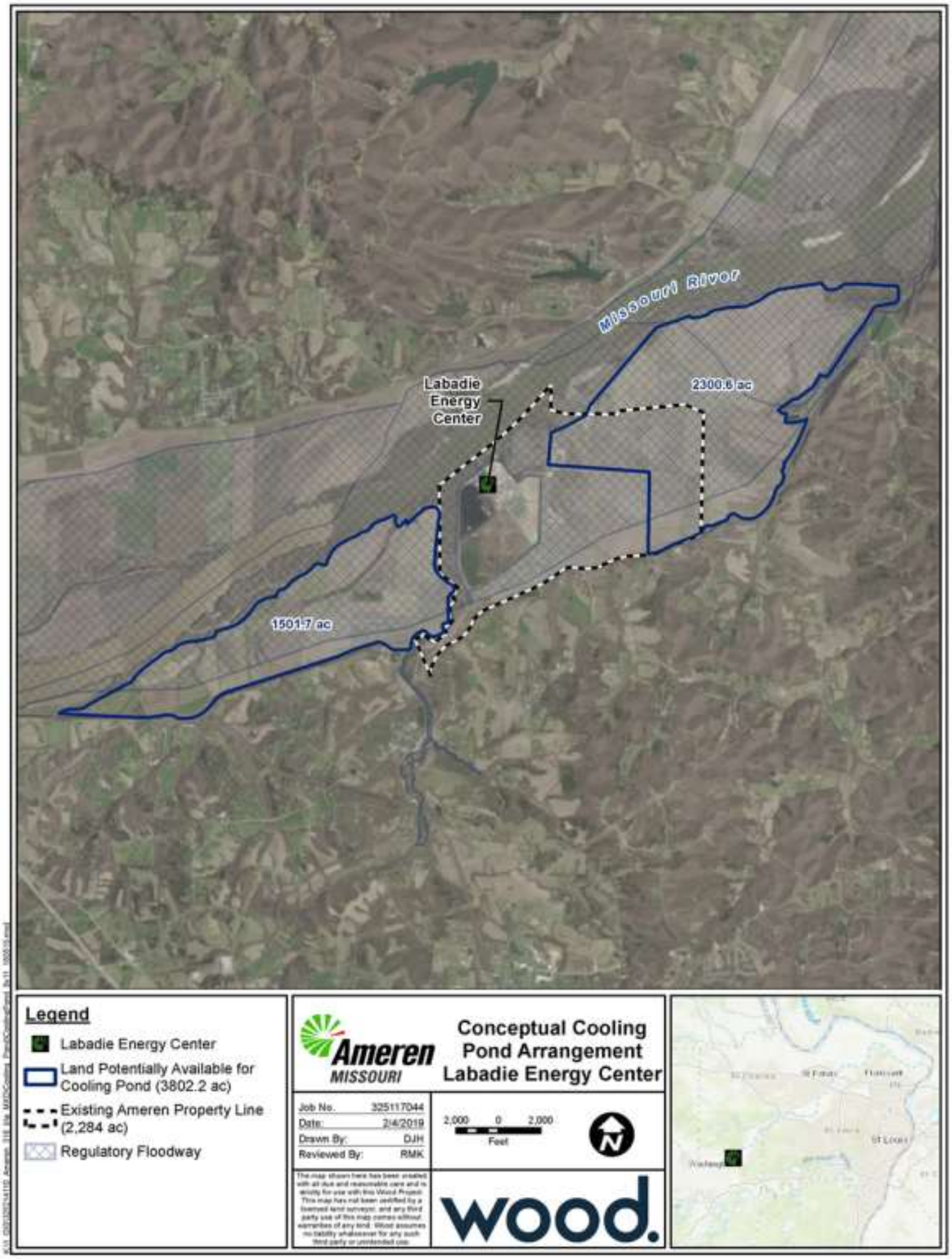


Figure 10.4. Conceptual Cooling Pond Arrangement

10.3.2 Closed-Cycle Cooling Towers

The closed-cycle cooling study (B&M 2018) investigated several types and arrangements of cooling towers and made a determination regarding the feasibility of that technology at LEC. The study considered LEC's plant parameters and the age and condition of the existing equipment for compatibility with various cooling technologies. The study provided a cost estimate consistent with the Association for the Advancement of Cost Engineering (AACE) Class 5 cost estimate for each alternative and developed a list of candidate technologies for further investigation and a more detailed Class 4 cost estimate. Class 5 cost estimates are characterized as conceptual screening estimates with a pricing accuracy range of -50% to +100%. Class 4 estimates are characterized as study or feasibility estimates with a pricing accuracy range of -30% to +50%.

10.3.2.1 Natural Draft Cooling Towers

The closed-cycle cooling study concluded that natural draft cooling towers were most likely technically feasible for retrofit at LEC (B&M 2018). Natural draft cooling towers have no forced air current from fans and rely on hyperbolic vertical stacks to create air current using rising warm air at the base to induce cooler air at inlets near the bottom. To achieve this effect, the stacks must be very tall (> 500 ft.). Because the stack is very tall, plume issues such as fog and icing are notably reduced as compared to mechanical draft cooling towers. Natural draft cooling towers are considered to be feasible at LEC but are not the preferred cooling tower arrangement based on higher cost and impracticality of installing a very tall cooling tower.

10.3.2.2 Dry Cooling

Dry cooling uses air to condense steam turbine exhaust. Both direct and indirect cooling was investigated but was deemed to be infeasible for retrofit at LEC because heat exchangers must be mounted in close proximity to the turbines to keep system pressures manageable (B&M 2018). Based on the existing configuration of plant components, there is insufficient available space near the turbines to install heat exchangers. In addition, dry cooling typically results in poorer cooling efficiency than wet cooling because dry cooling is based on ambient dry bulb temperature, which is typically higher than wet bulb temperature. Because this option was considered to be infeasible at LEC this technology was eliminated from further consideration.

10.3.2.3 Plume Abated (Hybrid) Mechanical Draft Cooling Towers

Plume abated mechanical draft cooling towers are similar to conventional mechanical draft cooling towers except they include plume reduction technologies that remove moisture content from the exhausted air. The method by which the moisture is removed varies from vendor to vendor. In some cases, coils are used to cool a portion of the water by a dry method to remove a portion of the moisture from the air. In such cases, the towers are a type of "hybrid" cooling using both wet and dry cooling. These types of towers can be located closer to other infrastructure that may be at risk from fog and icing concerns. At the LEC, the closed-cycle cooling study (B&M 2018) made the determination that locating the cooling towers closer to the plant and installing plume abatement technology was more expensive than the traditional mechanical draft cooling tower listed above. Plume abated (hybrid) mechanical draft cooling towers are feasible at the LEC but are not the preferred cooling tower arrangement.

The Rule lists “hybrid” cooling as an alternative type of cooling technology that should be investigated. The closed-cycle cooling study (B&M 2018) determined that plume abated (hybrid) mechanical draft cooling towers “are the most cost-effective hybrid tower for retrofit, and therefore other types of hybrid cooling (i.e., parallel hybrid cooling) were not evaluated.” Additional investigation into the feasibility of other “hybrid” cooling tower alternatives was not performed and is not necessary for this study. Hybrid cooling is considered to be feasible at the LEC, but it is not the preferred cooling tower alternative based on higher cost than other alternatives.

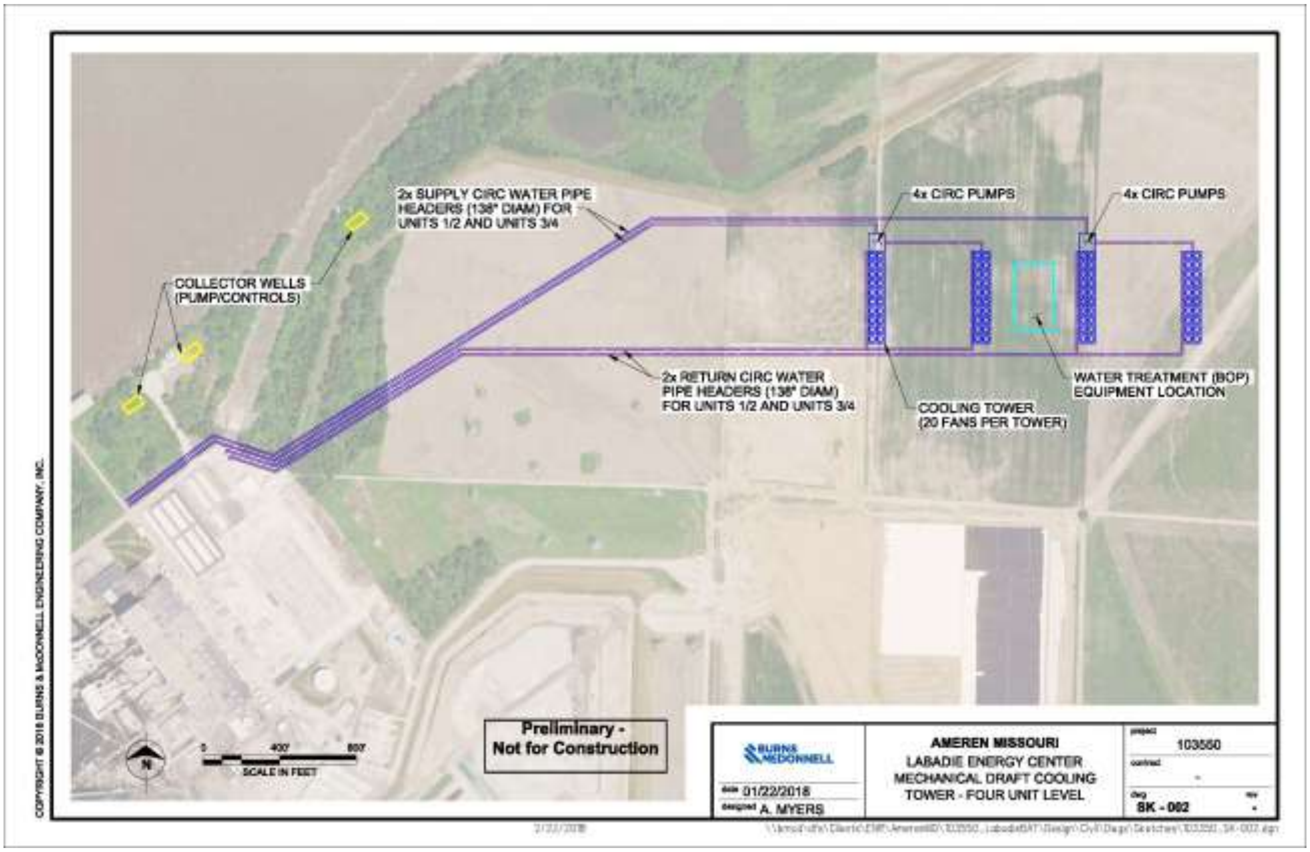
10.3.2.4 Mechanical Draft Cooling Towers

The closed-cycle cooling study selected counter flow, film fill, mechanical draft cooling towers as the most feasible, implementable in scale and the most cost-effective cooling tower arrangement at LEC when compared to the other cooling tower alternatives (B&M 2018). The logic behind this determination is provided in the closed-cycle cooling study (Appendix 10B). Mechanical draft cooling towers are the most widely used type of cooling tower arrangement at power plants in the Midwest. They are the most advantageous because the mechanical draft fans make them suitable for the regional environmental/weather conditions. Furthermore, LEC already owns the land necessary for implementation.

Exhaust air from cooling towers has a high moisture content and can cause fog and ice problems when ambient air temperature is low. LEC is in a relatively low-density area and Ameren already owns sufficient land to locate the towers in an area a sufficient distance from the plant where plume abatement is unnecessary. The closed-cycle cooling study (B&M 2018) determined that the additional cost to install the towers at a greater distance from the plant is lower than the cost for plume abatement technology that would be needed if the towers were installed immediately adjacent to the plant. The cooling system would become closed loop, and the necessary make-up water would be provided via groundwater collector wells. Mechanical draft cooling towers were therefore considered to be both feasible and cost effective.

10.3.2.5 Closed-Cycle Cooling Tower Option Retained for Further Analysis

The close-cycle cooling study (B&M 2018) investigated several types and arrangements of cooling towers and determined that counter flow, film fill, mechanical draft cooling towers would be the most feasible, implementable in scale and the most cost-effective cooling tower arrangement at the LEC when compared to the other cooling tower alternatives. Other alternatives and arrangements were deemed infeasible or feasible but either not practical or had a higher cost than the selected alternative. As such, implementation cost, compliance cost and social cost were not developed for these other alternatives. Figure 10.5 depicts a theoretical arrangement for mechanical draft cooling towers and associated piping developed in B&M 2018. The design requires new cooling towers, collector wells, pumps and interconnecting piping, new condenser water boxes, a new makeup water system and new water treatment systems (and chemical feed), new electrical power supply systems, new building structures, and waste disposal cost. The details of the design are described in detail in Section 5.2.4 of B&M 2018. A summary of the design basis parameters is provided in Figure 10.6. The design would place the cooling towers north of the plant on land currently owned by Ameren and currently utilized for agriculture. As previously stated, the location was selected to place the cooling towers at a sufficient distance from the plant so that the exhaust plume would not be problematic and plume abatement technology would not be necessary. The cooling tower array includes four new 480 ft. by 88 ft. concrete cooling towers with 52 ft. tall cooling towers. Eight new 4,200-HP pumps would be required in the cooling tower pump structure. The system would require 18,000 ft. of interconnecting 138-inch diameter pipe and 4,000 ft. of 96-inch diameter pipe. Because this design provides make-up cooling water from collector wells the existing CWIS is not needed and could be decommissioned. This study provides an implementation schedule, compliance cost and social cost for non-plume abated mechanical draft cooling towers.



Source: B&M 2018

Figure 10.5. Conceptual Mechanical Draft Cooling Tower Arrangement

Technology Option	**Mechanical Draft/PA Cooling Tower (Low/High)**
Tower Type	Counterflow, H/E fill
Number of Cells (per tower)	20-mechanical draft 28-plume abated
Tower Dimension (each)	480 ft (L) x 88 ft (W)) / 672 ft (L) x 98 ft (W)
Design Wet Bulb	79.9 °F
Design Approach (+2°F recirc allowance)	7°F
Design Range	24.8°F
Water Flow Rate (each)	251,500 gpm
Drift	0.0005%
Plume Abatement	Included for PA option
Level	Level 1
Design	35F dry bulb, 90% RH
Plant Modifications	• Upgrade condenser waterboxes • Several specialized tie-ins for large circ water pipe • Electrical modifications
Circ. Water Pipe Largest Diameter	138 inches (all units) / 96 inches (one unit)
Circ Water Pumps	New: 2 to 8
Design Flow Rate (per pump)	125,500 gpm
Design TDH	108 ft – 112 ft (varies) / 106 ft – 110 ft (varies) PA
Water Treatment	Clarification/filtration (4 COC), chem feed
Raw Water Source	Collector well(s)
Electrical Design	Substation/345 kV xmfr; 4160/480swgr/MCC

Source: B&M 2018

Figure 10.6. Conceptual Mechanical Draft Cooling Tower Design Basis Parameters

10.3.2.6 Closed-Cycle Cooling Implementation Schedule

Implementation of closed-cycle mechanical draft cooling towers at the LEC is expected to take 96 months or eight years to complete design, permitting, procurement, construction and start-up for all four units (B&M 2018). The work would be accomplished in phases and each unit would be converted to closed-cycle cooling individually over the course of those eight years. The first unit would take the longest due to design and permitting steps. The following three units would repeat the design and implementation process (B&M 218). Equipment procurement is an important element of the schedule. Increased demand in the industry for cooling towers and ancillary equipment as a result of 316(b) could affect the supply available in the market and further lengthen the schedule. The outage time for each generating unit to be converted to closed-cycle cooling is estimated at three to six weeks (B&M 2018). These outages would be staggered as described above.

10.3.2.7 Compliance Cost

The B&M study provided an indicative site-specific Class 4 cost estimate for mechanical draft cooling towers based on development of the following considerations:

- Major mechanical, electrical and civil quantities for cost estimating purposes.
- Additional consideration of site-specific criteria that affected scope and budget.
- Budgetary quotes and sizing information from major equipment vendors including cooling towers and transformers.
- Cost for engineering, owner cost and permitting are included.
- O&M cost include both fixed and variable cost

Table 10.4 summarizes the estimated cost for mechanical draft cooling towers at the LEC. Complete information regarding the cost estimate is available in Appendix 10B (see Section 5.0 of B&M 2018). Because B&M 2018 presents cost in 2018 dollars and this report is intended to present cost in current (2019) dollars, Wood, using an annual inflation estimate of 2.70% (based on the Handy-Whitman Index - Capital Cost Escalation Factor) for one year, has estimated the 2019 cost for the same cost estimate. In order to provide life-cycle cost, parameters are provided by B&M 2018 and summarized in Table 10.5 below. Table 10.6 presents the estimated life-cycle cost for mechanical draft cooling towers at LEC over a 30-year span. Additional details regarding the calculation of life-cycle cost are presented in B&M 2018.

Table 10.4. Estimated Project Cost for Mechanical Draft Cooling Towers

Item Description	Cost (2018 Dollars)	Cost (2019 Dollars)
Total Direct Cost	$258,900,000	$265,900,000
Total Indirect Cost	$46,800,000	$48,100,000
Total Project Cost	$420,500,000	$431,900,000
Annual O&M Cost	$14,700,000	$15,100,000
Total Life-Cycle Cost	$851,000,000	$874,000,000

Table 10.5. Life Cycle Cost Parameters

NPV Analysis Parameter	Value	Source
Analysis Duration	30 years	Ameren/Industry Exp
Cost of Capital/Discount Rate	5.94%	Ameren Economics
Capital Cost Escalation	2.4%	Handy-Whitman Index*
O&M Cost Escalation	2.5%	Industry Experience
Capacity Factor (each unit)	82%	Historical Labadie Values

*Handy-Whitman Index of Public Utility Construction Costs, 2017

Table 10.6. Life-Cycle Compliance Cost Summary for Mechanical Draft Cooling Towers

Item Description	Cost (2018 Dollars)	Cost (2019 Dollars)
Total Project Cost Including Owner Cost	$420,500,000	$431,900,000
30-Year O&M Cost (NPV)*	$430,500,000	$442,100,000
30-Year Project Life-Cycle Cost (NPV)	$851,000,000	$874,000,000

*** Calculated by Wood as the difference between total project cost and 30-year project life-cycle cost.**

10.3.2.8 Social Cost

The estimated social cost for the mechanical draft cooling tower alternative is presented in the social cost study (Appendix 10E) and summarized in Table 10.7 (Veritas 2019). The total social cost range is from $307 to $592 million depending on the discount rate applied.

Table 10.7. Total Compliance Cost and Social Cost for Mechanical Draft Cooling Towers

	Compliance Costs[a]		Social Costs (Present Value)					
			Electricity Price Increases Resulting From					
Discount Rate	Total Design, Construction, & Installation Costs	Annual O&M Costs	Compliance Costs	Power System Costs	Externality Costs[b]	Government Regulatory Costs	Total Social Costs	Annual Social Costs
3%	$431.9M	$15.1M	$494.0M	$98.0M	—	$0.074M	$592.1M	$30.21M
7%	$431.9M	$15.1M	$255.8M	$51.3M	—	$0.061M	$307.1M	$24.75M

[a] Compliance costs are undiscounted and in 2019 dollars. The social costs associated with the technology are discounted at 3 and 7 percent using the specifications outlined in Table 1 of the social cost study (Veritas 2019).

[b] The analysis does not include quantified estimates of the social costs resulting from externalities. Externality costs include decreases in social wellbeing resulting from property value, recreation, human health, reliability, and water consumption impacts. These categories of social costs were beyond the scope of this analysis.

10.4. EVALUATION OF FINE MESH MODIFIED TRAVELING SCREENS

As stated in the Rule, engineering analyses under (r)(10) must evaluate the potential feasibility of fine mesh screens (≤ 2.0 mm). Screen technologies provide entrainment protection through exclusion and survivability. Exclusion of an organism is based on the screen mesh dimensions and the size of the organism. Survivability is based on the force with which the organisms are pushed against the screen (through-screen velocity) and the handling characteristics of the system that removes the organism from the screen and returns it to the source waterbody. Survivability can be difficult to evaluate as it is dependent on many variables. Both aspects, exclusion and survivability, play an important role when evaluating entrainment reduction screen technologies.

10.4.1 Traveling Water Screens

Conventional TWSs with 3/8-inch mesh are currently in use at the LEC. A change in operating procedures for continuous rotation and installation of "fish-friendly" features to the existing screens at the LEC is an option to comply with the (r)(6) impingement mortality reduction standard. Given the age, condition and arrangement of the existing TWSs, an investigation into the potential to retrofit the existing screens for entrainment protection by installing fine mesh panels was not performed. As such, implementation cost, compliance cost and social cost were not developed for this alternative and all TWS alternatives in this study assume the procurement of new modified TWSs.

The improvements needed to provide BTA for impingement mortality reduction at the LEC CWIS are described in paragraph §125.94(c)[5] of the Rule. For this study it is assumed that any alternative that includes procuring and operating new TWSs would also include all necessary BTA improvements described in §125.94(c)[5].

10.4.2 Fine Mesh Traveling Water Screens

The Rule requires that facilities evaluate the technical feasibility and incremental costs of installing and operating fine mesh screens with 2.0 mm or smaller openings for exclusion of eggs, larvae and juvenile fish as a means to reduce entrainment. The success of fine mesh screens for reducing entrainment numbers also depends on effective handling of the organisms and systems to allow the safe return to the river. Maximizing exclusion and survivability to reduce entrainment losses is a key consideration for feasibility. As such an evaluation was conducted of fine mesh TWS screen design alternatives considering both plant operational demands and relevant industry research regarding key parameters that typically dictate exclusion and survivability.

The operational implications of replacing the existing 3/8-inch mesh screens with a finer screen mesh must be carefully evaluated. Table 10.8 presents the approach velocities of the TWS. Important factors to consider include: changes in cooling water flow rates, through-screen velocity, differential pressure across the screen, and screen longevity and maintenance. Replacing the existing screen mesh with fine mesh will result in a TWS with reduced percent open area. Offsetting this reduction in percent open area can be mitigated in four ways:

- ► Reducing cooling water demand through operational measures;
- ► An increase in cooling water velocity through the TWS;

- Install TWS screen with a different configuration that increases screen surface area within the same bay (i.e. dual-flow TWS conversion);
- Expand the intake by constructing a parallel or a new intake structure with enough screen surface area to make up for the constriction.

Table 10.8. Existing TWS Approach Flows and Velocities

Parameter	Value	Parameter	Value
DLWL Flow (cfs)	263	MWL Flow (cfs)	280
DLWL Velocity (gross, fps)	1.34	MWL Velocity (gross, fps)	1.13

The design of the existing CWIS and the use of constant speed vertical circulating pumps that draw water out of an open well would result in higher through-screen velocities if modified fine mesh TWSs are installed in the existing CWIS. Table 10.9 summarizes the calculated increase in through-screen velocities as a result of installing more restrictive fine mesh screen TWSs in the existing CWIS while maintaining the same CWS flow rate. These calculations are based strictly on the general dimension of the screen bay and the percent open area as supplied by various TWS manufacturers. The increase in through-screen velocity is likely to increase impingement rates and negatively impact impingement survivability. As such, a key assumption is that the increases in through-screen velocity shown in Table 10.9, for the sake of installing smaller mesh screens, is counterproductive to the intent of the Rule and is unlikely to yield a reduction in entrainment losses. Biological effectiveness of fine mesh is addressed in greater depth in Section 10.5.

Table 10.9. Theoretical Through-Screen Velocities

Mesh Opening	3/8-inch (existing)	2.0 mm x 2.0 mm	1.0 mm x 1.0 mm	0.5 mm x 0.5 mm
Net Open Area (Percent Reduction)	68.0%	51% (-25%)	44% (-35%)	39% (-43%)
DLWL Velocity (Percent Increase)	1.96	2.62 (+33%)	3.03 (+55%)	3.42 (+74%)
MWL Velocity (Percent Increase)	1.67	2.22 (+33%)	2.58 (+55%)	2.91 (+74%)

Head loss can also be an important consideration for screen analysis. Data provided by vendors indicate that head loss values through the screens is never more than a few inches for most screen arrangements and mesh sizes. The head loss through the screens was minor when compared with the elevation fluctuations that take place in the river. Debris load is expected to vary seasonally and the potential for head loss under conditions of high debris load is greater. However, the assumed operational condition for §316(b) is that screens are rotating continuously with a dual stage screen wash system. Therefore, it is assumed that debris loads will be managed more actively in the future and head loss fluctuation will be minimized even if smaller mesh is installed. As such, head loss through TWSs was not a significant factor in this study.

As a result of these considerations, an analysis of methods to expand available screen surface area in order to maintain the existing cooling water flow rate, maintain plant generation capacity and maintain the existing through-screen velocities was performed.

10.5. BIOLOGICAL EVALUATION OF FINE MESH TRAVELING WATER SCREEN SIZE

Important factors related to the selection of screen technologies that contribute to the survivability of larvae and eggs include the developmental stage, the size of the organism, the size of the screen mesh and the approach screen velocity. While reduced screen mesh size has increasing benefits of excluding larvae and eggs from being entrained, they also result in a “transfer” of potentially entrained organisms to those that are subject to losses associated with impingement (EPRI 2010a; EPRI 2013). Survivability of various species at various life stages (including natural mortality rates) is further discussed as part of the (r)(11) studies.

10.5.1 Biological Effectiveness of Fine Mesh Screens

As a component of the feasibility review of technology options, the effectiveness of a range of fine mesh screens was evaluated. While the Rule calls for the consideration of several fine mesh options (e.g. TWS and wedge-wire), actual practicality is contingent on whether or not the technology is effective in enhancing biological survival of potentially entrained organisms. This section evaluated the biological effectiveness of several fine mesh TWS alternatives (i.e., 2.0, 1.0, and 0.5 mm mesh sizes) given that wedge-wire cylindrical T-screens are not considered a practical alternative at the LEC (see Section 10.7).

10.5.1.1 Collection Efficiency and Retention Survival

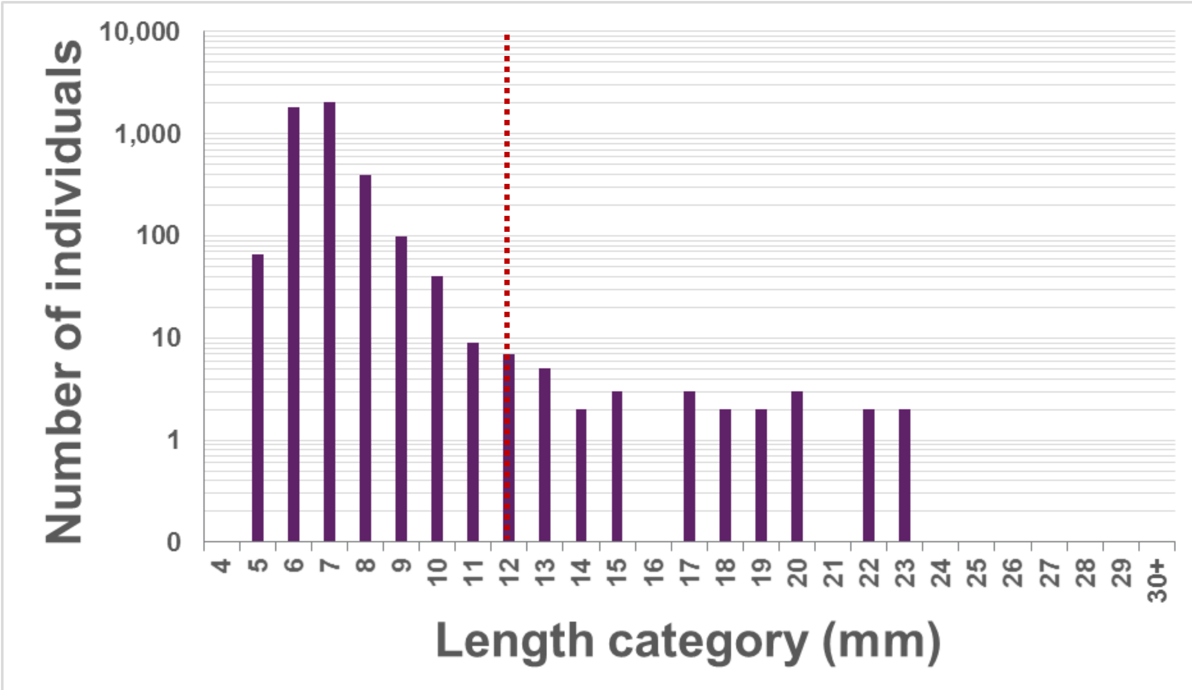
The efficiency of fine mesh TWSs in preventing entrainment is dependent on two factors: (1) screen mesh size that determines the number of organisms retained on the screens and (2) retention survival that is determined by biology (organism size and life stage, relative hardiness of species, etc.) and other considerations (approach velocity, impingement duration, etc.). Additionally, an evaluation of the effectiveness of the entire fine mesh TWS system must consider the performance and survival of organisms through fish return systems as they may impart additional stress, injury, or mortality to retained organisms before they are transferred back to the source waterbody. Retention of organisms on different screen mesh sizes can be conservatively estimated using the body depth of organisms exposed to the TWS. The deepest non-compressible portion of the body (i.e. head capsule) is often used to predict exclusion since larval fish are soft bodied and can be compressed. A substantial amount of variation exists in the morphometric characteristics among species making exclusion estimates species specific. Overall, decreasing screen mesh size reduces entrainment and increases screen retention of early life stages (eggs, larvae, and early juveniles) of fish and shellfish. However, large percentages of these excluded organisms are unlikely to survive retention on TWS and transport through fish return systems due to their extremely fragile nature. Recent laboratory studies by the Electric Power Research Institute (EPRI 2010a) have evaluated larval and early juvenile fish exclusion and survival on fine mesh (2.0, 1.0, and 0.5 mm) TWSs. Among the ten freshwater species tested, which were representatives from four separate families, fish having a total length of ≥ 12.0 mm consistently showed higher overall survival regardless of species, screen type, or approach velocity (EPRI 2010a). While this study did not take into account the potential negative effects on fish encountered by fish return systems, other independent EPRI studies (EPRI 2010b) suggest similar high survival for larvae ≥ 12.0 mm total length irrespective of return length, water velocity, and the presence of bends and drops in the fish return system. Increased survival of fish 12 mm and greater appears to be correlated with the development of juvenile-like characteristics around this stage including fin and scale development, and a general increase in body musculature (EPRI 2010a). Larger mesh sizes are more likely to exclude larger organisms that have developed to a point that they can survive the collection, handling and return process. Results from laboratory studies (EPRI 2010a; EPRI 2010b) have been corroborated by field evaluations of fish survival at facilities with fine mesh screens (see EPRI 2010a, 2013 and references cited within). For example, the 5-year study performed at Xcel Energy's Prairie Island Generating Plant to assess the effectiveness of fine mesh (0.5-mm) TWSs found that early developmental stages (prolarvae and postlarvae) showed the lowest survival of any life stage/developmental phase, whereas juveniles exhibited the highest survival (Kuhl and Mueller 1988).

10.5.1.2 Representative Taxa and Length Frequency Distribution

A review of the developmental stage and size distribution of collected ichthyoplankton in 2016 entrainment samples at LEC was performed to identify a mesh size that would be most beneficial in exclusion and survivability rates in a range of species. Size frequency distribution data and life stage analyses are presented below for a range of taxa that were among the most abundant species collected in 2016 entrainment samples at the LEC[1].

Invasive Asian carp species numerically dominated the 2016 entrainment samples at the LEC, with silver and bighead carp (*Hypophthalmichthys* spp.) together comprising 79.88 percent of the total ichthyoplankton collected. Silver and bighead carp larvae were initially encountered in early May and observed in entrainment samples through the end of the sampling period in September. Silver and bighead carp were found in a wide range of lengths (Figure 10.7). Approximately 96 percent of all silver and bighead carp specimens measured were less than 9 mm total length (TL). The majority of Asian carp larvae at these lengths are considered prolarval (yolk-sac stage), although silver carp larvae can be approximately 8.5 – 9 mm TL when yolk-sac is exhausted (Chapman 2006). No individuals were identified as juveniles (> 30 mm TL).

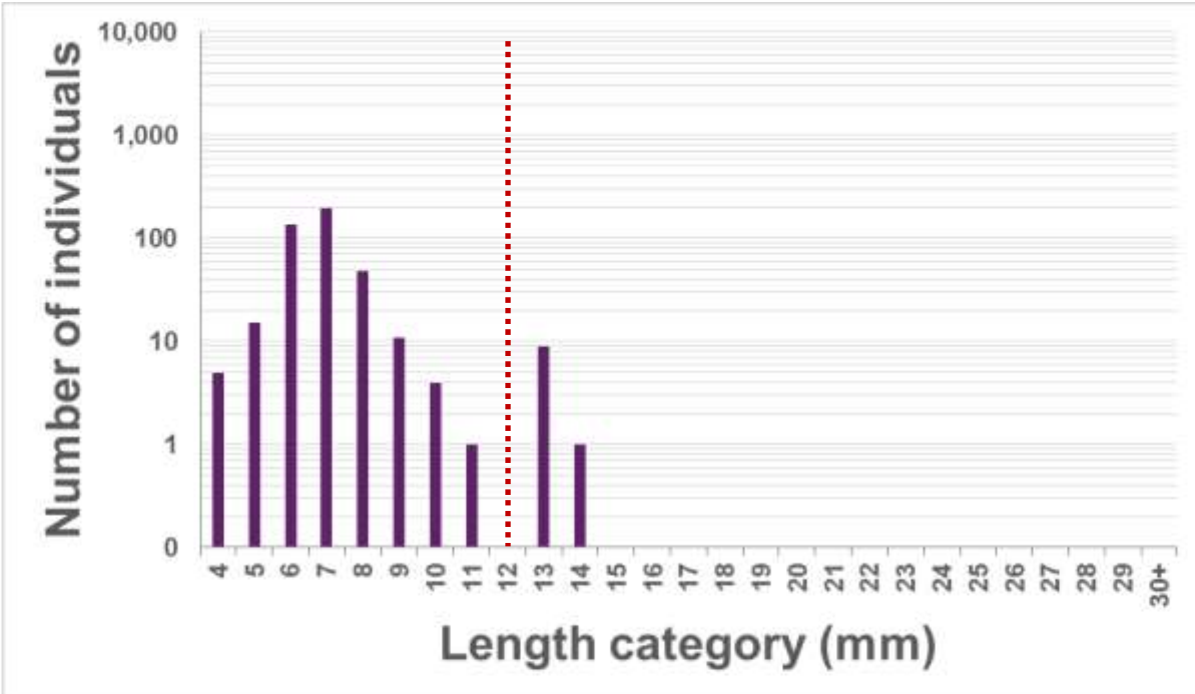
[1] Note, for the actual (r)(10) report, length frequency data and graphs will be derived from the companion (r)(9) report.



Note: The red demarcation line separates fish having a total length of ≥ 12.0 mm that consistently show higher overall retention survival rates across taxa (EPRI 2010a).

Figure 10.7. Length Frequency Distribution for Silver/Bighead Carp in 2016 Entrainment Samples at LEC

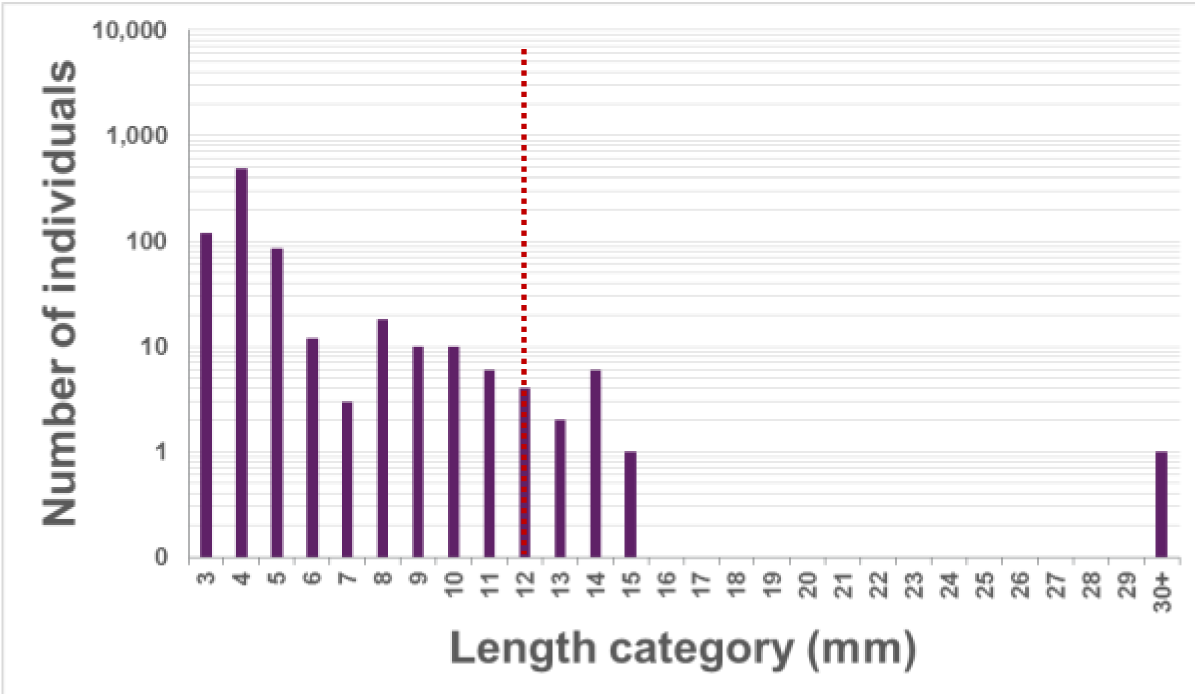
Carpsucker and buffalofish were among the most numerous specimens in early (i.e., mid-April through early May) entrainment samples at the LEC in 2016. Nearly all (96 percent) of carpsucker and buffalofish measured were less than 10 mm TL and considered yolk-sac larvae or recent post yolk-sac larvae (Figure 10.8). No juvenile individuals (> 20 mm TL) were collected.



Note: The red demarcation line separates fish having a total length of ≥ 12.0 mm that consistently show higher overall retention survival rates across taxa (EPRI 2010a).

Figure 10.8. Length Frequency Distribution for Carpsucker/Buffalofish in 2016 Entrainment Samples at LEC

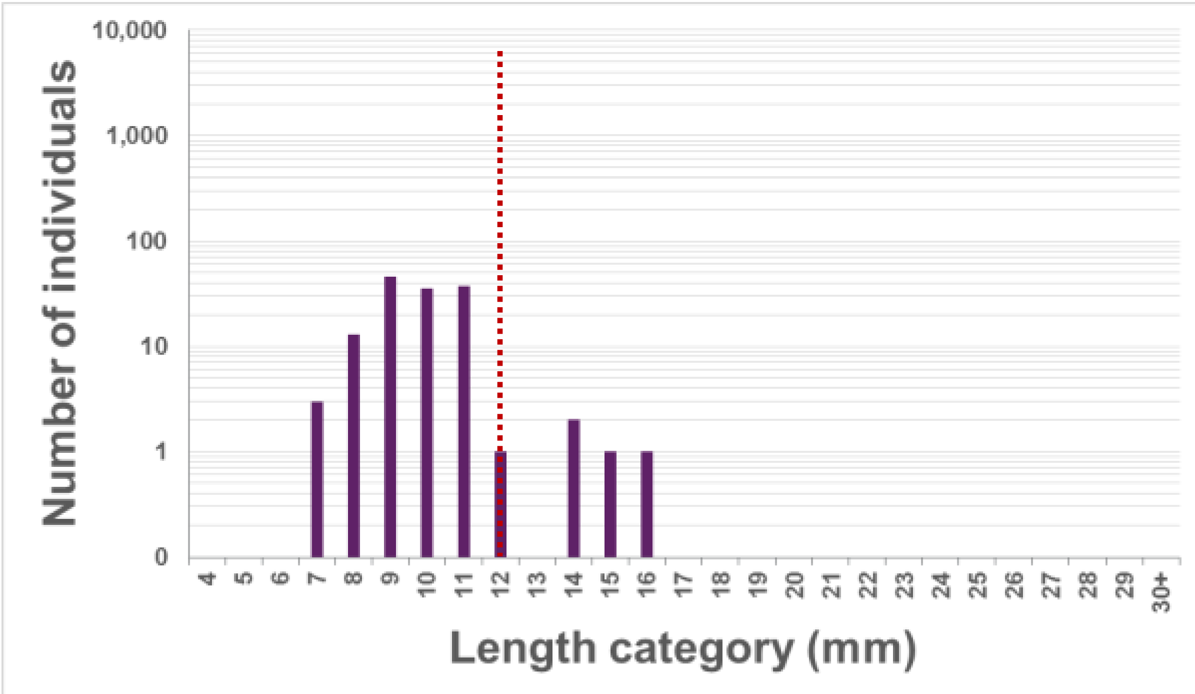
Freshwater drum larvae were collected in early June through early September in 2016 entrainment samples. Yolk-sac larvae measuring 3 mm - 3.9 mm TL represented 15.7 percent of measured specimens (Figure 10.9). Post yolk-sac larvae were most prevalent in collections and represented a wide range of sizes between 4 mm and 15.9 mm TL (Figure 10.9). However, most individuals (98 percent) were observed to be less than 12 mm. One juvenile freshwater drum measuring 40 mm TL was collected.



Note: The red demarcation line separates fish having a total length of ≥ 12.0 mm that consistently show higher overall retention survival rates across taxa (EPRI 2010a).

Figure 10.9. Length Frequency Distribution for Freshwater Drum in 2016 Entrainment Samples at LEC

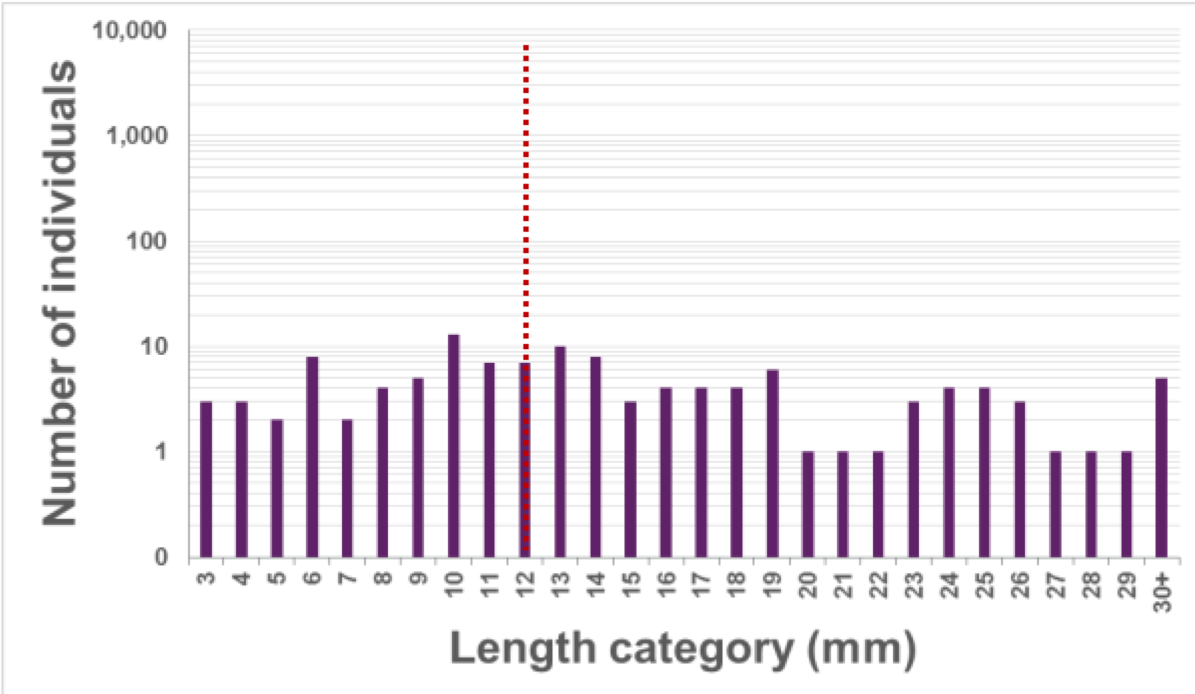
Goldeye and mooneye larvae were first observed in early May entrainment samples at the LEC and reached their peak densities by late May. They were not observed in samples after mid-June. Approximately 96 percent of mooneye and goldeye individuals measured were yolk-sac larvae measuring less than 12 mm TL. Lengths for all individuals measured ranged from 7 mm to 16.7 mm TL (Figure 10.10). No juveniles (> 40 mm TL) were collected.



Note: The red demarcation line separates fish having a total length of ≥ 12.0 mm that consistently show higher overall retention survival rates across taxa (EPRI 2010a).

Figure 10.10. Length Frequency Distribution for Mooneye/Goldeye in 2016 Entrainment Samples at LEC

Clupeids (e.g., gizzard shad) were first observed in early May samples and reached their peak density in early June. Clupeids continued to be collected through early August. Yolk-sac (3 mm – 5.9 mm TL), post yolk-sac (6 mm – 24.9 mm TL) and juvenile (> 25 mm TL) life stages of gizzard shad were measured in collections, with lengths ranging from 3.3 mm to over 33 mm TL (Figure 10.11). Most individuals measured (i.e., 80 percent) were post yolk-sac larvae.



Note: The red demarcation line separates fish having a total length of ≥ 12.0 mm that consistently show higher overall retention survival rates across taxa (EPRI 2010a).

Figure 10.11. Length Frequency Distribution for Clupeids (e.g. Gizzard Shad) in 2016 Entrainment Samples at LEC

10.5.1.3 Estimated Retention of Organisms at LEC on Fine Mesh TWS

Length frequency data (presented in Section 10.5.1.2) from 2016 entrainment sampling at the LEC were used along with predicted percent retention (exclusion) estimates derived using head capsule depth methods (EPRI 2010a; EPRI 2014) to estimate the numbers of individuals excluded on three mesh sizes (Table 10.10). Retention was maximized by the 0.5 mm screen mesh (71.8 to 98.8 percent). The 1.0 mm mesh size had the second highest overall retention, but retention was notably reduced 91.8 to 6.1 percent. Notably, the 2 mm screen mesh resulted in the poorest retention (0.3 percent overall) as compared to other mesh sizes.

Table 10.10. Estimated Number of Excluded Individuals for Three Mesh Sizes (2.0, 1.0, and 0.5-mm) Based on 2016 Entrainment Data at LEC*

Species or Taxa	Total Number of Individuals	Number Excluded			Percent Excluded		
		2.0 mm	1.0 mm	0.5 mm	2.0 mm	1.0 mm	0.5 mm
Asian carp (silver/ bighead)	39,806	38	2,151	36,380	0.1%	5.4%	91.4%
Minnow spp.	54	2	14	49	3.7%	25.9%	90.7%
Buffalofish	136	1	25	134	0.7%	18.4%	98.5%
Carpsucker	232	0	2	196	0.0%	0.9%	84.5%
Carpsucker/Buffalofish	1,529	44	155	1,309	2.9%	10.1%	85.6%
Gizzard shad†	122	15	74	106	12.3%	60.7%	86.9%
Goldeye/ Mooneye	168	2	77	166	1.2%	45.8%	98.8%
Freshwater drum	941	37	111	676	3.9%	11.8%	71.8%
Totals	**42,988**	**139**	**2,609**	**39,016**	**0.3%**	**6.1%**	**91.8%**

*Note: These analyses are based on only measured individuals rather than flow-adjusted entrainment estimates.
† Gizzard shad is considered a fragile species under §125.92 of the final rule due to reduced impingement survival rates even when the BTA technology of modified traveling water screens are in operation.

10.5.2 Considerations of Approach Velocity

It is important to note the difference between the terms approach velocity and through-screen velocity when evaluating their impact on the survival of organisms. Approach velocity is the velocity of the fluid ahead of the screens. Through-screen velocity is the velocity of the fluid through the actual pores in the screen. The research cited in this section refers to approach velocity as an indicator for survivability. However, the engineering analysis and feasibility in this study is based on calculation of through-screen velocity. For the most part, the Rule only refers to through-screen velocity. In almost all cases approach velocity is less than through-screen velocity as it is a direct relationship between the percent open area of a screening system. At the LEC that relationship may not hold true and the velocity through the stop gates upstream of the TWS likely have a significant effect on approach velocity. For the impingement standards, approach velocity is likely a key indicator of the capacity for escape, but through-screen velocity is likely an indicator of an impinged fish's ability to survive the handling and return process. For entrainment (the focus of this study) it is assumed that eggs and larvae are impinged on fine mesh screens and must be properly handled and returned to the source waterbody. In that scenario, through-screen velocity is likely an indicator for survivability because it establishes the force with which the organisms are pushed into the screen. In some cases, at high through-screen velocities, forces could cause organisms that were initially impinged to be extruded through the screen mesh and become entrained. Knowing that most research is based on approach velocity and, in general, approach velocity is less than through screen velocity, it was conservative to base the analysis and design considerations on through-screen velocities.

Among parameters affecting survival (such as organism size, approach velocity, and impingement duration), approach velocity has also been shown to play a role in larval impingement survival, particularly for smaller larvae, although the magnitude of that effect is highly variable and dependent upon species (EPRI 2010a). Recent laboratory testing by EPRI (2010a) of three different approach velocities (0.5 fps, 1.0 fps, and 2.0 fps) showed a general trend towards decreasing survival as velocity increased with a marked drop in survival at velocities of 2.0 fps or greater, but relationships were not always significant. In cases where approach velocity had a significant effect on survival, the treatments with 0.5 fps had significantly greater survival than treatments with 1.0 fps (EPRI 2010a). Until additional studies are conducted to better understand the effects of approach or through-screen velocities on the survival of fish eggs and larvae impinged against fine mesh screens, this study is recommending that any fine mesh screen analysis be based on not increasing the current through-screen velocity currently experienced at the LEC. Currently through-screen velocities range from 1.67 fps at MWL to 1.96 fps at DLWL. We believe this is a rational course of action based on the research that is currently available.

10.5.3 Summary of Biological Considerations of Fine Mesh Screen Effectiveness

Overall, the 0.5-mm screen mesh size demonstrates the highest retention (and likely the highest potential survival benefit) for all life stages and dominant taxa collected at the LEC. Larger larvae (> 12.0 mm TL) have shown higher retention survival rates regardless of species, screen type, or approach velocity (EPRI 2010a) and higher survival rates through fish return systems (EPRI 2010b). However, very few larger (> 12.0 mm TL) larvae were collected in 2016 entrainment samples at the LEC that would have been excluded by larger screen mesh sizes. Based on observed length frequency data of larvae entrained at the LEC, the 0.5-mm screen mesh size is considered to be the mesh dimension with the overall greatest retention (and likely survival benefit) across a range of species encountered at the LEC. Considerations of the differential benefits of each screen mesh option will be evaluated separately in (r)(11).

10.6. MODIFICATIONS TO THE INTAKE STRUCTURE TO ACCOMMODATE FINE MESH

The preferred alternative for installation of fine mesh at the LEC is one that increases available screen surface area enough to accommodate design criteria favorable to entrainment reduction and plant operations. The complexity and cost incurred to provide additional screen area correlates to the magnitude of the gross screen area increase. Based upon the research and analysis described in Sections 10.4 and 10.5, the following are considered to be critical design criteria for potential modifications to the CWIS and TWS that will provide a reasonable opportunity for entrainment reduction:

- Screen mesh size: Fine mesh of 2.0 mm or smaller. The preferred size to maximize exclusion is 0.5 mm but larger sizes will be considered for technical feasibility.
- Through-screen velocity: equal to or less than the current calculated through-screen velocity
- Total cooling water flow: 280 cfs at MWL (263 cfs at DLWL)

A number of technical alternatives were considered that expand gross screen area to achieve these stated design criteria. These alternatives are presented below. Notably, the 1.0 mm mesh option was eliminated from consideration because it did not allow for full DIF when installed within the existing CWIS (when holding through-screen velocity constant) and the low exclusion rate (when compared to 0.5 mm mesh) did not justify consideration for an expansion of the CWIS.

10.6.1 Convert Existing Traveling Water Screens to Dual-Flow units

To maintain the current flow rate and through-screen velocity using a 2.0 mm x 2.0 mm fine mesh screen with an open area of 51%, the gross screen area would need to be increased by 33%. Preliminary analysis of available screen alternatives indicates that it may be possible to install dual-flow conversion screens in the existing CWIS and increase screen surface area by an additional 20-30%. The design of dual-flow conversion TWSs offers greater screen surface area by allowing water to enter two opposing sides of the same TWS. Conversion units are designed to be installed into an existing CWIS with through-flow TWSs. Further analysis would be required to determine the precise extent of additional screen surface area that could be provided, and it would be limited by vendor design and dimensional constraints of the existing intake channel. A preliminary design for a dual-flow unit provided to Wood by a reputable TWS vendor was five and one half feet of screen surface per side, for a total of 11 feet of screen width. A larger screen may be attainable with a more refined design. For the purpose of this study, installation of dual-flow conversion TWSs is considered conceptually feasible and would provide sufficient cooling water flow and through-screen velocity to sustain current plant operations. However, more detailed analysis may invalidate this alternative.

Under this option the existing CWIS would need to be modified to accommodate the dual-flow screens. The required modifications are substantial, but when compared to other technologies alternatives studied in this report, they are much less costly. At a minimum the floor slab upstream from the existing screen would have to be partially demolished and modified to allow for installation of a dual-flow TWS. Other modifications to the CWIS may also be required or could be beneficial. For example, it would be advantageous to place the screens as far downstream from the stop gates as possible, without encroaching on and disrupting flow to the pumps. Locating the screens at a distance downstream from the stop gates would be beneficial because the fluid dynamics of a dual-flow screen are far more complex than a through-flow screen where idealized one-dimensional flow conditions are assumed. In a dual-flow arrangement, the water in the intake channel is forced to split around the screen's nose cone into relatively narrow side channels to get to the screens. The velocity in these side channels is expected to be quite high compared to the actual through-screen velocity. Screen manufacturers claim that research on the shape of the nose cone has helped to develop near laminar flow through the screen mesh. At the LEC the presence of the two stop gates further complicates the flow characteristics. Therefore, there are notable uncertainties regarding the ability to implement this technology based on the above referenced flow characteristics within the existing CWIS, complex hydraulics and the resultant through-screen velocity. For implementation at the LEC, modeling, either computer or physical (scale) modeling, may be necessary to ensure the desired impingement survivability results are achieved. The cost for modeling and physical alterations of the CWIS is included in the cost estimate presented in Section 10.6.1.2.

The research presented in Section 10.5 indicates that potential entrainment reduction (via exclusion) by adding 2.0 mm fine mesh is minimal because the vast majority of eggs and larvae are smaller than 2.0 mm and would continue to be entrained. However, 2.0 mm mesh is considered "fine mesh" by the Rule and the conversion of the TWS to dual-flow with 2.0 mm fine mesh is retained as a technically feasible alternative because it represents the greatest potential entrainment reduction possible within the physical limits of the existing CWIS. Therefore, this technical alternative is retained for further consideration in the (r)(11) and (r)(12) studies.

This arrangement offers the following advantages compared to the other alternatives:

- Lowest capital and maintenance cost of the fine mesh alternatives
- Provides same cooling water flow rate as currently used at the LEC
- Can likely be accomplished without an outage. Requires the least amount of alterations to the existing CWIS
- All work is contained within the existing CWIS and permitting is likely not required
- Does not require modifications of the existing cooling water pumps
- Does not require new cooling water pumps
- Does not require alteration of the existing condenser piping system
- The dual flow screen arrangement has the potential to reduce debris carry over into the LEC's condenser piping system

Disadvantages of this alternative include:

- Requires structural modifications to the CWIS to accommodate dual flow screens
- High degree of uncertainty regarding the gross screen surface expansion that is possible
- High degree of uncertainty regarding flow characteristics and through-screen velocity due to complex hydraulics

- Complex hydraulics and above uncertainty correlates to a high degree of uncertainty regarding survival benefits

10.6.1.1 Dual-Flow Conversion Implementation Schedule

It is expected that it would take three years to convert the existing TWSs to dual-flow conversion TWSs and install the supporting infrastructure. The first year would be used for design, permitting and procurement of improvements and new screens. The second year would be spent upgrading and installing infrastructure improvements to support the fish return system, including improving the fish collection trough and installing the new river fish return trough. It is expected that the eight replacement dual-flow screens would be installed over a two-year period starting in year two, with half the screens installed each year. Installation of individual screens could be undertaken during planned unit outages. Unit outages to install this alternative are not anticipated.

10.6.1.2 Compliance Cost

On behalf of Ameren Missouri, Black & Veatch (B&V) completed a technical memorandum, B&V Project 193718, on November 4, 2016 (B&V 2016) that details the requirements and costs for impingement compliant TWSs and a BTA fish return system at the LEC. The memorandum, provided in Appendix 10D, is titled “Fine Mesh Screen Evaluation” but the mesh sizes proposed in the report typically did not represent fine mesh in accordance with the Rule. Therefore, the findings of the report are considered to be applicable to impingement compliance screen replacement alternatives and cost. The costs in the B&V memorandum were completed based on cost quotes from various vendors and various types of TWSs, which included dual-flow conversion screens. Readers of this study are encouraged to review B&V 2016 in its entirety. Many screen vendors reported that the cost difference between a TWS with nominal mesh and a TWS with fine mesh is insignificant. Therefore, the B&V memorandum is referenced for costing and technical details associated with upgrading the existing LEC CWIS with new TWSs that include fine mesh screen panels.

The B&V memorandum does not provide the necessary details and costing to modify the CWIS by installing the dual-flow conversion screens and maximizing the potential gross screen surface area available, as discussed above. A detailed engineering analysis would need to be completed to determine the extent of the work required to retrofit the CWIS to accommodate dual-flow conversion screens. Wood has estimated the cost for these structural modifications.

The cost summary provides a total project cost and estimated total O&M cost in NPV over a 30-year duration. All TWSs include new traveling screens equipped with fish buckets, dual stage screen wash spray and a fish collection and return system. The O&M cost includes: general operational costs, planned major equipment maintenance and replacement, estimated unplanned equipment maintenance and replacement, and energy consumption from the spray wash pumps and screen drives (@ 75% capacity factor). O&M costs vary greatly year to year based on the planned and unplanned equipment replacement costs. The estimated annual average O&M cost is $280,000. It should be noted that to achieve compliance Wood is assuming all TWSs will rotate continuously during normal operations to maximize impingement survivability. This is expected to have a notable effect on CWIS O&M cost when compared to current operations. However, it is expected that the O&M cost for fine mesh TWSs would be similar to O&M cost for impingement compliant screens as provided in 40 CFR §125.94(5).

Table 10.11 presents the escalation rates that were applied in developing NPVs.

Table 10.11. Net Present Value and Escalation Values

Item	Escalation Factor
Discount Rate	5.94%
Capital Cost Escalation Rate	2.70%
O&M Escalation Rate	2.50%
Energy Escalation Rate	2.10%
Life Cycle Duration	30-Years

B&V (2016) used 2016 dollars for its cost estimate. Wood, using an annual inflation estimate of 2.70% (based on the Handy-Whitman Index - Capital Cost Escalation Factor) for the past three years, has estimated the 2019 cost for the same cost estimate. The estimated project costs for installing 2.0 mm fine mesh dual-flow conversion TWSs are provided in Table 10.12.

Table 10.12. Estimated Capital Cost for 2.0 mm Dual-Flow Conversion TWS

Item Description	Cost (2019 Dollars)
Average Total Project Cost w/ 30% contingency (2016 Dollars)[1]	$15,201,500
Total Project Cost Adjusted for Three Years of Inflation at 2.71%	$16,500,000
Estimate for CWIS Modification for Dual-Flow Screen Install	$3,000,000
Total Direct & Indirect Cost	**$19,500,000**

[1] Source: B&V 2016

Table 10.13 presents the life-cycle compliance cost summary for this alternative. A sum of 30-year O&M costs are provided in NPV. O&M costs vary greatly year to year based on the planned and unplanned equipment replacement costs. The estimated annual average O&M cost is $280,000. The total 30-year life-cycle cost for this alternative is presented as a sum of project cost and O&M cost.

Table 10.13. Life-Cycle Compliance Cost Summary for 2.0 mm Dual Flow Conversion TWS

Item Description	Cost (2019 Dollars)
Total Project Cost	$19,500,000
30-Year O&M Cost (NPV)	$5,500,000
30-Year Life-Cycle Cost (NPV)	$25,000,000

10.6.1.3 Social Cost

Estimated social cost for this alternative, which includes installing 2.0 mm fine mesh dual-flow TWSs into the existing CWIS, is presented in the social cost study (Veritas 2019) included in Appendix 10E and summarized in Table 10.14. There are no expected power system costs for this alternative because this operating condition would be the same as the expected minimum future operating condition for impingement compliance, with eight modified TWSs continuously rotating and being sprayed with a dual stage spray wash system. The total social cost ranges from $16.2 to $8.8 million depending on the discount rate applied.

Table 10.14. Total Compliance Cost and Social Cost for 2.0 mm Dual-Flow Conversion TWS

	Compliance Costs[a]		Social Costs (Present Value)					
			Electricity Price Increases Resulting From					
Discount Rate	Total Design, Construction, & Installation Costs	Annual O&M Costs	Compliance Costs	Power System Costs	Externality Costs[b]	Government Regulatory Costs	Total Social Costs	Annual Social Costs
3%	$19.5M	$0.28M	$16.2M	—	—	$0.003M	$16.2M	$0.83M
7%	$19.5M	$0.28M	$8.8M	—	—	$0.003M	$8.8M	$0.71M

[a] Compliance costs are undiscounted and in 2019 dollars. The social costs associated with each technology are discounted at 3 and 7 percent using the specifications outlined in Table 1 of the social cost study (Veritas 2019).

[b] The analysis does not include quantified estimates of the social costs resulting from externalities. Externality costs include decreases in social wellbeing resulting from property value, recreation, human health, reliability, and water consumption impacts. These categories of social costs were beyond the scope of this analysis.

10.6.2 Expansion of Cooling Water Intake Structure

In order to install 0.5 mm fine mesh TWSs and provide the plant with sufficient CWS flow, the CWIS must be expanded to provide greater gross screen surface area. Several alternative arrangements for the expansion of the CWIS to accommodate 0.5 mm fine mesh by providing greater screen surface area and maintaining the existing through-screen velocities were conceptualized. For this level of hypothetical analysis one alternative was selected for further development, as presented in Appendix 10A. This indicative design is intended to represent a reference point for size, scale and cost for expansion of the CWIS to support 0.5 mm fine mesh TWSs. It is reasonable to assume that further study and refinement of the design may result in a CWIS expansion that is different than what is presented in Appendix 10A. The theoretical design entails the construction of new intake bays with trash racks, gates and modified fine mesh through-flow TWSs flanking the existing CWIS. New forebays would be constructed to channel water into the existing CWIS bays. The trash racks and TWSs would be removed from the existing bays. The existing pumps and condenser piping system would remain and continue to operate. The overall design includes 14 new 12-foot-wide screen bays to accommodate the flow and velocity requirements. The total length of the new intake would be approximately 420 feet long.

A fish handling and return system would be installed for all bays. A warm water, recirculating piping system would be installed to minimize the potential for icing. As indicated in the figure included in Appendix 10A, the number of bays is split evenly between upstream and downstream of the existing CWIS to minimize width in the channel leading to the existing CWIS. The current design is based on the assumption that the TWSs have zero percent blockage from debris and fouling, which was also assumed for development of the through-screen velocity calculations for the existing TWSs. This assumption is made with the understanding that future operation of the TWSs, to be effective at impingement and entrainment reduction, would rotate continuously and be cleaned with a dual stage spray wash system. During further design development it would be possible to increase gross screen area to account for blockage from debris or periodic closure of individual intake bays for service, while maintaining the required DIF.

This expansion would also entail impacts to riparian zones and instream habitats and would require extensive environmental reviews and permitting in conjunction with Sections 401/402/404 of the CWA, Section 10 of the Rivers and Harbors Act, Section 106 of the National Historic Preservation Act, and Section 7 of the ESA.

While 0.5 mm fine mesh screens represent the greatest ability to prevent entrainment of organisms it is also reasonable to assume that it will lead to an increased difficulty in operating and maintaining the proposed CWIS. The sediment and debris load in the Missouri river is likely to lead to a high rate of screen clogging and damage. The O&M cost estimate provided below is intended to account for this difficulty but with seasonal and annual changes in river conditions the O&M cost could vary significantly from season to season and year to year. This arrangement offers the following advantages compared to the other alternatives:

- Provides same cooling water flow rate as currently used at LEC
- Can be accomplished with minimal outage time because the existing CWIS can be operated while the flanking structure is constructed
- Easily scalable to a wide range of screen velocity/screen area alternatives
- Requires minimal alterations to the existing CWIS. All major construction is performed outside of the existing CWIS.
- Does not require modifications of the existing cooling water pumps
- Does not require new cooling water pumps
- Does not require alteration of the existing condenser piping system

Disadvantages of this alternative include:

- Fish handling on the upstream side of the CWIS must be piped past the downstream intakes for safe return to the river
- Significant change in CWIS footprint size
- High capital cost and a high degree of uncertainty for maintenance cost
- Significant permitting challenges

10.6.2.1 CWIS Expansion Implementation Schedule

It is expected that it would take five years to complete such a sizeable expansion of the CWIS. Design, permitting and bidding activities would be completed during the first two years. Construction, including procurement of screens and other equipment, would be completed during the last three years. It is estimated a single TWS manufacturer would require a year to deliver fourteen (14) 12-foot-wide through-flow screens. If supplies for TWSs are limited due to competing 316(b)-related retrofits at other facilities, that procurement schedule could be extended. Any potential design could allow for staged implementation of screens for an individual unit. A unit could potentially be duty ready in three years. It is expected that with this design the unit outage time required for conversion would be minimal, if not avoidable all together. This schedule also allows for starting the required two-year optimization study that must be performed during years four and five. The findings of the study could be implemented when other screens are brought online. However, the actual schedule for implementation of the optimization study is expected to be dependent upon specific NPDES permit conditions

10.6.2.2 Compliance Cost

An AACE Class 4 cost analysis of the modified and expanded CWIS was developed. To accommodate the flow restrictions resulting from installation of very small fine mesh (0.5 mm), the CWIS must be expanded to provide the same CWS flow as currently utilized. The cost summary shown in Table 10.15 provides a total project cost. All TWSs include new traveling screens equipped for continuous operation, with fish buckets, dual stage screen wash spray and a fish collection and return system. The O&M cost includes: general operational costs, planned major equipment maintenance and replacement, estimated unplanned equipment maintenance and replacement, and energy consumption from the spray wash pumps and screen drives (@ 75% capacity factor). It should be noted that to achieve compliance Wood is assuming all TWSs would rotate continuously during normal operations to maximize impingement and entrainment survivability. This is expected to have a significant effect on O&M cost when compared to current operations. This is also expected to have a higher O&M cost than impingement compliance in (r)(6) because the number of screens and pumps is greater.

Table 10.15. Estimated Capital Cost for 0.5 mm Fine Mesh CWIS Expansion

Item Description	Cost (2019 Dollars)
Civil	$4,100,000
Structural	$11,250,000
Architectural	$600,000
Equipment (Screens and Accessories)	$12,500,000
Process Piping	$1,300,000
Electrical	$1,000,000
Instrument and Controls	$600,000
HVAC and Building Mechanical	$350,000
Construction Expenses	$650,000
Engineering	$3,250,000
Scope Development	$1,600,000
Construction Management	$3,350,000
Permitting	$1,100,000
Owner’s Cost	$850,000

Contingency (15%)	$6,375,000
Total Direct and Indirect Cost	**$48,875,000**

Table 10.16 presents the life-cycle compliance cost summary for this alternative. A sum of 30-year O&M costs are provided in NPV. The total 30-year life-cycle cost for this alternative is presented as a sum of project cost and O&M cost.

Table 10.16. Life-Cycle Compliance Cost Summary for 0.5 mm Fine Mesh CWIS Expansion

Item Description	Cost (2019 Dollars)
Total Project Cost	$48,875,000
30-Year O&M Cost (NPV)	$9,700,000
30-Year Life-Cycle Cost (NPV)	$58,575,000

10.6.2.3 Social Cost

Estimated social cost for this alternative, which includes installation of 0.5 mm fine mesh through-flow TWSs into an expanded CWIS, is presented in the social cost study (Veritas 2019) included in Appendix 10E and summarized in Table 10.17. The total social cost ranges from $39.7 to 21.6 million depending on the discount rate applied.

Table 10.17. Total Compliance Cost and Social Cost for 0.5 mm Fine Mesh CWIS Expansion

	Compliance Costs[a]		Social Costs (Present Value)					
			Electricity Price Increases Resulting From					
Discount Rate	Total Design, Construction, & Installation Costs	Annual O&M Costs	Compliance Costs	Power System Costs	Externality Costs[b]	Government Regulatory Costs	Total Social Costs	Annual Social Costs
3%	$48.9M	$0.49M	$37.0M	$2.7M	—	$0.009M	$39.7M	$2.02M
7%	$48.9M	$0.49M	$20.1M	$1.4M	—	$0.007M	$21.6M	$1.74M

[a] Compliance costs are undiscounted and in 2019 dollars. The social costs associated with each technology are discounted at 3 and 7 percent using the specifications outlined in Table 1 of the social cost study (Veritas 2019).

[b] The analysis does not include quantified estimates of the social costs resulting from externalities. Externality costs include decreases in social wellbeing resulting from property value, recreation, human health, reliability, and water consumption impacts. These categories of social costs were beyond the scope of this analysis.

10.6.3 Seasonal Installation of Fine Mesh Screen Overlays

Seasonal installation of fine mesh screens to exclude eggs and larvae during the critical spawning periods each year has been implemented at other power generation facilities. In order to evaluate the feasibility and logistics of application of seasonal installation of fine mesh screens at the LEC, information regarding compatibility of screens with fine mesh overlays was acquired from various manufacturers. Some manufacturers can provide overlay screens to be installed over nominal mesh screens that are used the remainder of the year. Other manufacturers recommend removal of the nominal mesh screen panel and installation of fine mesh screen panels in their place. Regardless of the method, this approach requires labor hours and cost twice a year every year to install and remove the fine mesh. Important factors to consider when installing fine mesh screens seasonally include: changes in cooling water flow rates, through-screen velocity, differential pressure across the screen, trapping of debris between overlay and nominal screen, screen longevity and maintenance, and timing the installation of fine mesh with the annual spawning season. The effects on plant operations during the timeframe the overlays are installed need to be considered. At the LEC, the screen mesh size most likely to significantly reduce entrainment is 0.5 mm mesh. Reduction in the percent open area of traveling screens from installation of 0.5 mm mesh is estimated at 43 percent (Table 10.9). This reduction in percent open area would result in the following unfavorable outcomes if installed in the existing CWIS:

- Reduced through-screen percent open area results in a corresponding reduction of available cooling water if through-screen velocities are maintained at current levels. Such a reduced flow rate would increase thermal effluents, resulting in either NPDES permit exceedances or plant de-rating. This topic is discussed in greater depth in Section 10.11. Alternatively,
- Sustained cooling water flow rates (i.e., held at existing levels) would result in an increase in through-screen velocity if fine mesh screens are installed. The theoretical increase in through-screen velocity is presented in Table 10.9. The increase in through-screen velocity is likely to increase impingement rates and negatively impact impingement survivability. As such, a key assumption is that the increases in through-screen velocity of a magnitude shown in Table 10.9, for the sake of installing smaller mesh screens, is counterproductive to the intent of the Rule and is unlikely to yield a reduction in entrainment losses.

For these reasons, seasonal installation of fine mesh screens on the existing TWSs is considered infeasible.

10.7. WEDGE-WIRE CYLINDRICAL T-SCREENS

The application of a passive wedge-wire screen system is an alternative to traveling screens. Wedge-wire systems have: 1) a sufficiently small slot size to physically block passage of the smallest life stages to be protected; 2) low through-slot velocity (i.e., the water velocity between wedge-wire slots) to minimize the hydraulic zone of influence in which passive or weak swimming organisms can become entrained; and 3) an adequate ambient velocity (i.e., “sweeping” velocity) passing across a screen to carry organisms and debris along and away from the screen.

Typically, wedge-wire T-screens are deployed at low volume intakes or in deep, clean water bodies for high volume facilities. In order to develop the type, size and location of a potential wedge-wire screen array, pertinent biological and CWS flow data was provided to a wedge-wire T-screen manufacturer in order to determine the size and number of screens required. The vendor was provided with DIF flows for each pump. Based on available sampling data presented in Section 10.5, a 0.5-mm slot width was selected because it provides the highest potential exclusion rate. Screens with larger slot widths (1.0 mm and 2.0 mm) are available. Those sizes would reduce the number of screens necessary and the overall footprint of the array; however, they would not block passage of the smallest organisms. Industry standard through-screen velocity design standard for wedge-wire is 0.5 fps and complies with 40 CFR § 125.94(c)(2) for impingement compliance.

The conceptual design includes a total of 56 wedge-wire cylindrical T-screens. Each screen would be eight feet in diameter and approximately 26 feet long. It should be noted this is the minimum number of screens required. To account for damaged or blocked screens a more complete design should include additional screens or longer screens to provide additional redundancy. The screens would be constructed of stainless steel to inhibit corrosion and biofouling. The screens would be oriented to ensure flow along the length of the slots to help minimize debris build-up on the wedge-wire screen modules. Each screen would be attached to a manifold piping system to combine flow from each screen and carry the water to the CWIS and the CWS pumps. The screens and piping system would be supported by pile foundations in the river bed. The CWIS would be modified by closing the intake bays to accept the intake pipe (or pipes) and removing the existing trash rack and TWSs. The screen system would also be supplied with an integrated self-cleaning airburst system that consists of an air compressor, storage tanks, air distribution, and timer control system. Under air burst conditions, air would be rapidly released on the interior of the wedge-wire cylinders periodically to blow off or dislodge any minor debris or sediment attached to the surface.

An array with screens attached to a fixed bulkhead constructed in front of the CWIS was not considered because there is not sufficient space to accommodate the required number of screens. Instead the array is conceptualized to be deployed horizontally in the river. Deployment of the screen array transverse to the river channel is not practical because it would extend into the navigation channel. Instead, the array would be deployed linearly along the bank adjacent to the CWIS. Because of the number of screens, it is expected that the array could be up to 2,000 linear feet long. Even if aligned along the bank, conflicts with commercial and recreational watercraft and impact damage to the screen array could still occur and create safety concerns for boat traffic in the river.

In addition to the small screen slot size, another advantage of the passive wedge-wire system over the traveling screen system is a reduction in machinery. The wedge-wire system requires no traveling screen motors, spray wash pumps or fish return system. In addition, the system requires only enough electricity to power the airburst system. In fact, there would be a net reduction in energy consumption compared to current CWIS power requirements and the power requirements of a modified traveling screen described in Section 10.6.

However, there are several concerns regarding the installation of wedge-wire screens at the LEC:

- *Damage from Large Woody Debris*. Notably, the Missouri River is characterized as having a high debris load, particularly during flood events, that represent a high risk for infrastructure installed within the river, as shown in Figure 10.12. Large woody debris—often whole trees—are commonly transported during flood events and represent a real hazard for damage to an installed configuration of wedge-wire screens. While debris deflection systems may be considered for installation to protect the wedge-wire array, they do not fully mitigate the risk for damage. It is possible that many screens could be disabled in a single event (i.e., flood). The time frame to procure, fabricate and install replacement screens could limit the LEC's generating capacity in an unpredictable way that would have a potential impact on plant viability.

Note: During the 2011 Missouri River Flood, trees were carried downstream by flood waters, and soil beneath railroad tracks was eroded causing them to collapse. U.S. Army Corps of Engineers photo by Diana McCoy.

Figure 10.12. Damage Observed After Rushville Sugar Lake Levee in Missouri Was Breached During the 2011 Missouri River Flood

- *Sediment and Debris Accumulation.* Assuming that a debris deflection system were installed, it is expected that such a system would create areas behind the deflection system that are characterized as having reduced water velocities. Such low velocity areas (eddies, etc.) would accumulate sediments and additional debris that would result in a reduction in current and create a buildup of sediment in and around the screens. Fouling of the screen surface could be controlled to an extent with the airburst system. However, there would be occasions when large and small debris, heavy sediment, and ice (Daly, 1991) would not be cleared by airburst alone, and manual cleaning or dredging would be required. Screens would therefore have to be inspected, cleaned and repaired by divers both regularly and on an emergency basis. Given the debris load in the river (Jacobson et al., 2009) and potential for ice accumulation in winter (Daly, 1991), there would be no reliable way to predict the maintenance and screen replacement needs in a given year. Thus, the forecasting of annual maintenance budgets would be highly speculative and unreliable.

- *Conflict with Navigation*. An array with these dimensions could conflict with navigation and would require approval by the USACE and the U.S. Coast Guard. It is uncertain whether this type of array would be approved, and if so, these agencies may impose requirements that could significantly alter the design and cost of the project.

In summary, the application of a cylindrical wedge-wire T-screen array of this size being installed in a waterbody similar to the Missouri River is not common and a similar example was not identified during research efforts. For the reasons listed in this section, the installation of a wedge-wire intake system at the LEC is considered impractical.

10.8. POTENTIAL REUSE OF WATER

Alternative sources of cooling water, including process water, grey water, waste water, reclaimed water, or other sources were investigated to determine if these could be supplied in sufficient quantities to reduce river water intake. Publicly available discharge permits within Franklin County were researched. Table 10.18 summarizes the sites with outfall flow rates greater than 10,000 gallons per day (GPD). The volume of discharge water provided by the sites listed below is not significant enough to consider for use at the LEC to reduce river water intake flows. Furthermore, many of the Wastewater Treatment Plants (WWTPs) and Wastewater Treatment Facilities (WWTF) identified are at a significant distance from the LEC and the conceptual extension of pipelines to deliver wastewater would be notably longer and result in significant disruptions to the natural and human environment. Because sufficient sources available for reuse of water are limited in their supply and insufficient in meeting the cooling water demands of the LEC, this alternative is considered to be infeasible and is eliminated from consideration.

Table 10.18. Potential Sources of Water Reuse

Permitted Outfall	Daily Outfall (Actual Flow)	Distance (straight line)
Labadie Energy Center	>950 MGD	NA
Offsite Sources of Grey Water		
Gray Summit WWTP	14,100 GPD	5 Miles
Union East WWTP	185,000 GPD	11 Miles
Union West WWTP	1.1 MGD	12 Miles
Washington WWTF	2.3 MGD	8 Miles
Catawissa WWTP	74,000 GPD	10 Miles
Robertsville WWTP	32,000 GPD	10 Miles
Berger WWTP	13,986 GPD	28 Miles
Franklin County Public Water Supply District #1 Krakow Area	99,103 GPD	13 Miles
Total	**3.8 MGD**	**0.4% of Labadie Flow**

10.9. GROUNDWATER

10.9.1 Physical Setting

The LEC is located in physiographic landforms comprised of floodplains of the Missouri River. Soils in this region include loamy, silty and clayey alluvium. The Missouri River floodplains are bound on the south by the River Hills Physiographic Province, which consists of loess-covered uplands. According to the on-line Geologic Map of Missouri (Missouri Geological Survey On-line Geologic Map; Geostrat), the project site area is underlain by Quaternary-aged Missouri River alluvium that can extend to thicknesses greater than 100 feet. The upper bedrock is Ordovician-aged Jefferson City and Cotter Dolomites. The bluff areas south of the project location contain younger formations including Joachim Dolomite and St. Peter Sandstone.

According to Missouri Water Quality Assessment, Water Resources Report Number 47, groundwater resources in the project area include Missouri River Alluvium and the Salem Plateau Groundwater Province. The rocks comprising the aquifer within this Groundwater Province are also defined as the Ozark aquifer, and overlay the Ozark confining unit. The bedrock formations that comprise the Ozark aquifer in the project area include, from youngest to oldest, the St. Peter Sandstone, Everton Formation, Jefferson City/Cotter Dolomite, Roubidoux Formation, Gasconade Dolomite, Eminence Dolomite and Potosi Dolomite.

10.9.2 Aquifer Characteristics and Yield

10.9.2.1 Missouri River Alluvium

The Missouri River Alluvium is comprised of unconsolidated gravel, sand, silt and clay and averages 60 to 100 feet in thickness. Based on the variability of the materials, the Missouri alluvial aquifer can provide significant amounts of potable water. Wells within the alluvial aquifer can yield between 500 gpm to 2,000 gpm. Larger sustained yields could be obtained if wells are located near the River in areas of induced recharge.

Based on a review of the Missouri Well Information Management System (WIMS), no high capacity alluvial wells exist in the immediate vicinity of the project area. Water Resources Report No. 30 indicates that a 15-inch diameter well in the Missouri River Alluvium at Weldon Springs (approximately 25 miles downstream, north side of Missouri River) has a production capacity of approximately 2,600 gpm (3.7 MGD). Most municipalities rely on a combination of surface water, alluvial wells and bedrock wells. Alluvial wells are rarely used as a sole water supply source due to periodic flooding.

10.9.2.2 Bedrock Aquifer

The Ozark aquifer is capable of producing relatively high quantities of groundwater. In the general project area, numerous high capacity bedrock wells are utilized by industry or municipalities. The City of New Haven, Missouri, located approximately 24 miles upstream from LEC, operates two bedrock wells between 880 and 980 feet in depth with well yields between 450 and 500 gpm. The City of Washington, located approximately 12 miles upstream from the LEC, operates two bedrock wells with yields reportedly up to 2,000 gpm. Both of these municipalities are situated in areas with similar bedrock characteristics (types and thicknesses) to the project area.

10.9.3 Ability to Meet Minimum Water Requirements

Without the benefit of a site-specific hydrogeologic investigation to determine aquifer characteristics, documented aquifer properties in the region indicate a potential maximum well yield of 2,600 gpm. In order to meet the LEC's DIF for cooling water flow of 1,005,400 gpm, an extensive wellfield consisting of approximately 400 large diameter wells and water storage facilities would be required. Considering drawdown and potential well interference issues, there is likely insufficient land area available for such a well field. Furthermore, high capacity groundwater extraction such as this is sometimes considered "water mining" and permitting at the state or local level may be problematic. If bedrock wells were utilized, considering the confined nature of the Ozark aquifer, the combined drawdown of groundwater from numerous wells would reach significant distances beyond the project area, lowering regional groundwater levels and affecting a large population base. Considering these factors, the sole use of groundwater as an alternative water supply for once-through cooling water is considered infeasible at the LEC. Consideration of groundwater, however, is retained as a potentially feasible component of an alternative that includes other technologies for reducing water use and entrainment.

10.10. OTHER TECHNOLOGIES

Other physical barrier technologies like Gunderboom Marine Life Exclusion System or porous dams (also known as leaky dikes) were excluded from consideration because they are not technically feasible at a scale as large as the LEC and not suited for installation in a water body like the Missouri River.

10.11. OPERATIONAL MEASURES

Changes in operational measures or procedures that have the potential to reduce entrainment mortality rates were investigated for this study. For large base-load plants with once-through cooling there are rarely modest changes that can be made that will significantly lower entrainment rates. The following section details analysis of some of these measures considered at LEC.

10.11.1 Flow Reduction

As an alternative to an expansion of the CWIS to accommodate installation of fine mesh screens, it is theoretically possible to implement operational measures at LEC that reduce the cooling water flow demand. In this scenario, through-screen velocities within the existing CWIS are maintained and flow is reduced proportionally in conjunction with dimensions of the fine mesh screens. Table 10.19 presents the values for percent open area used to calculate the resultant flow rates on a per pump basis based upon varying screen mesh sizes. The values in Table 10.19 reflect potential entrainment benefits by reducing the overall cooling water flow rate, resulting in a proportional reduction in entrained and impinged organisms. As with other fine mesh screen alternatives, variable reductions in entrainment are also achieved by exclusion of larvae and eggs based on mesh size (see Section 10.5).

Table 10.19. Flow Reduction with Fine Mesh Screens (Per Pump)

Mesh Opening	3/8 inch (Existing)	2.0 mm x 2.0 mm	1.0 mm x 1.0 mm	0.5 mm x 0.5 mm
Net Open Area (% reduction in open area)	68%	51% (-25%)	44% (-35%)	39% (-43%)
MWL Intake Flow (cfs)	280	210	182	160
MWL Intake Flow (gpm)	125,750	94,313	81,738	71,678
DLWL Intake Flow (cfs)	263	197	171	150
DLWL Intake Flow (gpm)	118,000	88,499	76,700	67,260

Note: calculations based on through-screen velocities of 1.67 fps at MWL and 1.96 fps at DLWL

10.11.2 Controlling Flow to Reduce Through-Screen Velocities

The design of the existing CWIS and the use of constant speed vertical circulating pumps that draw water out of an open well do not currently allow for the modulation of cooling water flow rates as shown above. Should more restrictive fine mesh screens be installed within the existing CWIS, the pumps will simply pull the same amount of water through the screens at a faster rate. As discussed elsewhere in this study, such an outcome is not desirable as it will likely result in a higher impingement rate. Therefore, modifications to achieve flow restrictions need to be implemented either with the pump or downstream of the pump as detailed below:

- Equip the pumps with variable frequency drives (VFDs) to reduce pump speed. (Note: it is not known if the existing pumps, motors, and electrical supplies are compatible with VFDs.)

- Install a bypass from the pump discharge (just downstream of the pump) to the pump intake (downstream from the TWS) effectively forcing the pump to recirculate the same water repeatedly, therefore reducing the intake of actual river water.
- Remove the existing motors and pumps and replace with new units sized for the new flow rate.
- Rebuild the existing pumps to lower the pump capacity by changing the impeller and other features. Based on the type, age and condition of the pumps, it is not known if this is feasible.
- Operate the 68-inch condenser water valves to achieve the desired flow. Example locations of these valves are shown in Figure 10.13. (Note: it is not known if the valves are capable of regulating flow.)

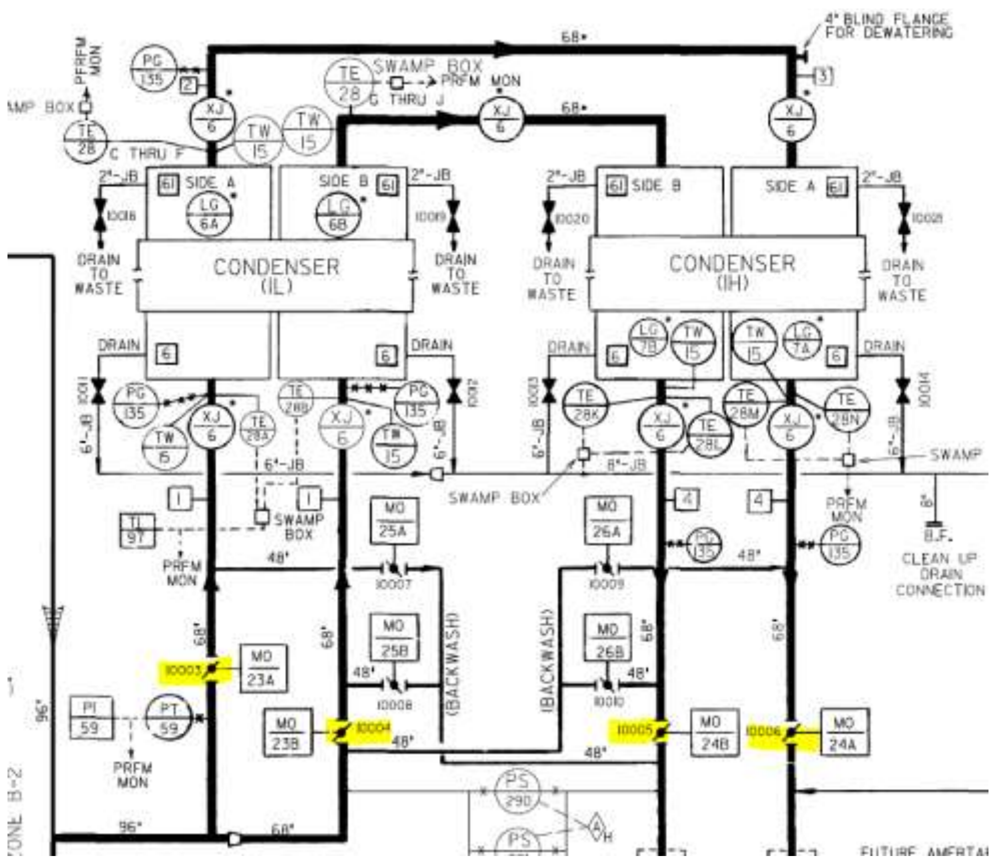


Figure 10.13. Condenser Piping System Configuration

Assuming one of these methods of controlling flow is feasible, the plant would have to operate continually (or seasonally) with a reduced amount of cooling water flow. The following sections analyze the impact to the LEC given such an operating restriction.

10.11.3 Consideration of Thermal Impacts on Cooling Water Discharge

Theoretically it would be possible to use less cooling water and still generate the same level of electrical output by rejecting the same heat load to less cooling water and discharging that water back to the source water body at a higher temperature delta.

The B&M 2018 study provides the following values:

- Maximum summer plant capacity cooling load: 3,101 million British thermal units/hour (MMBTU/hr) (one unit); 12,404 MMBTU/hr (all four units).
- At peak summer conditions, the plant adds approximately 24.8°F worth of heat to the intake flow and has maximum discharge temperature (to the discharge channel) of 112.9°F.
- Design cooling water flow: 251,425 gpm (one unit); 1,005,700 gpm or 2,240 cfs (all four units)

Using the equation Q = 500 x gpm x Delta T, at 251,425 gallons and Q = 3,101 MMBTU/hr, yields a temperature increase of 24.7°F, which matches the temperature rise observations. Using the peak cooling load of 3,101 MMBTU/hr and calculating the required gpm gives the flow rate values at different temperatures as summarized in Table 10.20.

Table 10.20. Estimated Flow Rate for a Given Change in Temperature

Temperature Delta (°F)	Calculated plant flow at 3,101 MMBTU/hr per unit (gpm)
22	1,127,600
23	1,078,600
24.7	1,005,700
25.5	972,900
26	954,200
27	918,800

Any reduction in flow due to the application of fine mesh screens will result in higher delta T. There would be other implications for this alternative, like higher condenser pressures or microbiological induced corrosion, because of build up in tubes that does not occur at higher flow rates.

10.11.4 Thermal Impact of Reduced Cooling Water Flow Rate

Using the equation Q = 500 x gpm x Delta T, the cooling load of 3,101 MMBTU/hr per unit, and the information for mesh sizes on the flow reduction, the Delta T for the screens is calculated as shown in Table 10.21.

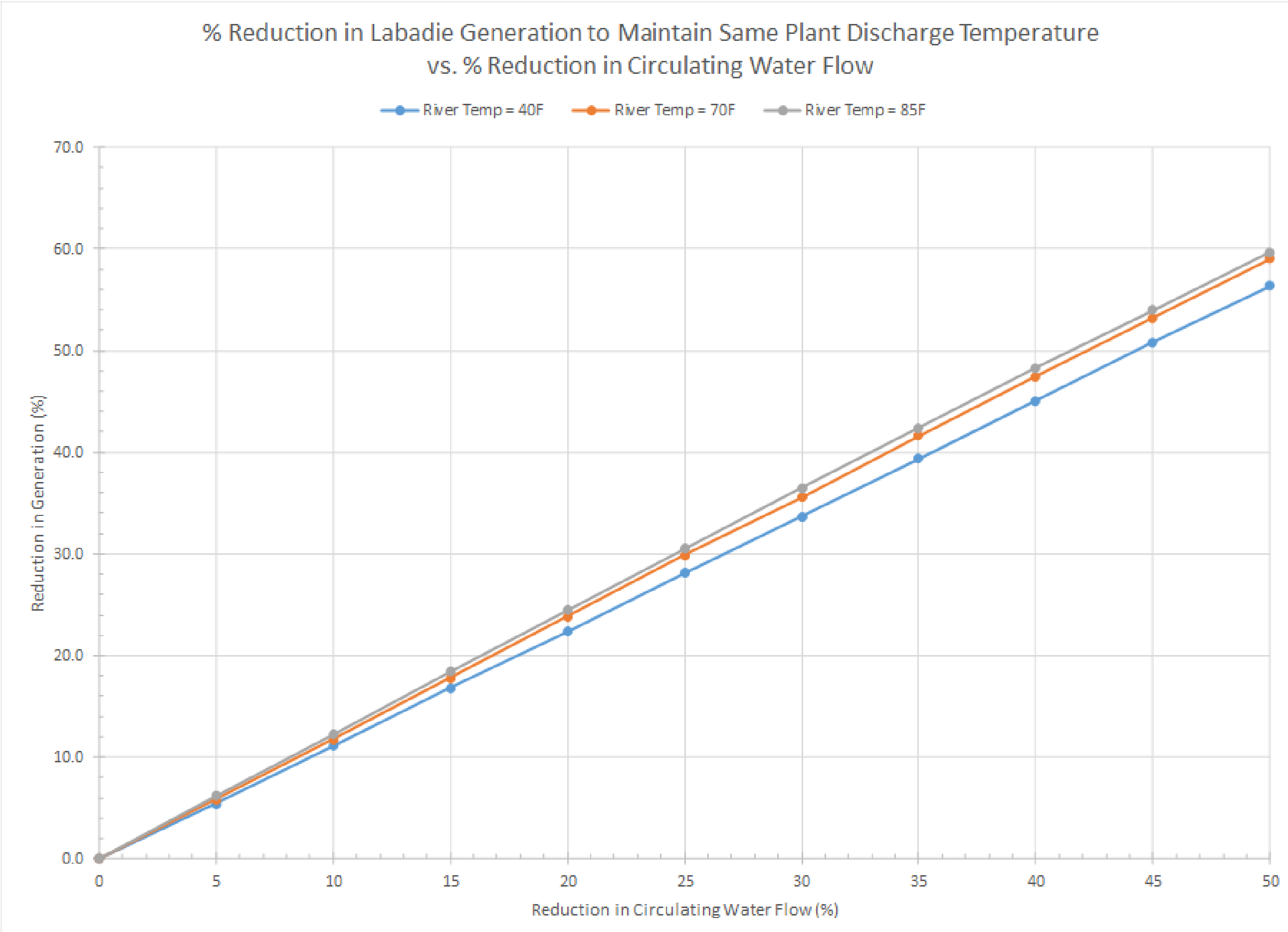
Table 10.21. Delta Temperature for Reduction of Flow Rate

Mesh Opening	3/8 inch (existing)	2.0 mm x 2.0 mm	1.0 mm x 1.0 mm	0.5 mm x 0.5 mm
MWL Intake Flow (gpm)	125,750	94,313	81,738	71,678
DLWL Intake Flow (gpm)	118,000	88,499	76,700	67,260
Delta T °F at MWL	24.7	32.9	37.9	43.3
Delta T °F at DLWL	26.3	35.0	40.4	46.1

Table 10.21 demonstrates the general range of effect of reduction of cooling water flow on discharge water temperature. The LEC's current NPDES permit includes thermal limits (316(a)) for discharge temperatures. Undoubtedly, the temperature increases indicated in this section represent potential exceedances of current thermal limits and would necessitate either plant derating or permit modifications. Because of the importance of the plant as a base-load facility, substantial derating is not practical. Additionally, substantial increases in thermal effluents would entail complex and problematic permitting revision that are considered to be impractical. For these reasons, it is deemed impractical to maintain plant generation capacity while reducing cooling water flow rates for fine mesh.

10.11.5 Power Generation Impact at Reduced Flow

The impact of reduced flow on generation capabilities (while holding delta T constant) at the LEC was also considered. Figure 10.14 represents the loss in generation capacity as a function of reduced cooling water flow rates (while holding Delta T constant).



Source: Ameren Missouri

Figure 10.14. Potential Reduction in Generation Capacity vs. Reduction in Cooling Water Flow Rate

The chart indicates that a 25% reduction in cooling water flow as a result of installation of 2.0 mm fine mesh (as shown in Table 10.19) would lead to an approximately 28% to 30% reduction in generating capacity at the LEC. The results of flow restriction from 1.0 mm and 0.5 mm mesh sizes were not analyzed in this study but it is reasonable to conclude that the results would include a derate that would impact unit viability based on the available flow. Because the Rule is not clear about the need to consider derating as a potential option under (r)(10), and because of the importance of the LEC's position within the Ameren fleet and the regional grid, this alternative was not considered further. As such, implementation cost, compliance cost and social cost were not developed for this alternative.

10.12. CONCLUSION

For a plant the size of the LEC with the absolute demand for generation and a very high cooling water flow rate, retrofitting to reduce or eliminate entrainment losses is typically complex and expensive. In addition, the nature of the Missouri River also reduces the available options for retrofit. The high sediment and debris load and the presence of the navigation channel impacted the practicality/reasonableness of several of the technology alternatives.

The technical feasibility of the following alternatives was considered to reduce entrainment losses at the LEC:

- Closed-cycle cooling
- Fine mesh screens with a mesh size of 2.0 mm or smaller
- Reuse of water or alternative sources of cooling water
- An evaluation of any other technologies for reducing entrainment as identified by the applicant or requested by the Director of the USEPA

Among those alternatives, the following were deemed technically feasible and practical for implementation:

- Mechanical Draft Cooling Towers
- Modified Dual-Flow TWSs with 2.0 mm fine mesh screen panels installed in the existing CWIS
- Expanding the CWIS and installing modified through-flow TWSs with 0.5 mm fine mesh screen panels

Entrainment losses could be reduced most significantly by conversion to closed-cycle cooling. This comes at extremely high capital and operating costs and reduces plant generation capacity mildly. At the LEC a closed-cycle cooling pond is not feasible due the size and orientation of available land and the significant difficulty associated with permitting in the floodway. Closed-cycle mechanical draft cooling towers were determined to be the most feasible, implementable in scale and the most cost-effective cooling tower arrangement at the LEC when compared to the other cooling tower alternatives. This alternative is representative of other cooling tower options (in terms of flow reduction) and is the lower cost option. It is therefore carried forward for further consideration as the closed cycle cooling alternative.

The analysis presented herein indicates that installing screen panels with smaller mesh in the existing CWIS can have a detrimental effect on the ability of the LEC to meet generation demand. Within the confines of the existing CWIS, the greatest possible screen expansion is via conversion of the existing once through TWS to dual-flow units with 2.0 mm screen mesh. Theoretically this would allow the plant to operate as it currently does and maintain the same through-screen velocities of the existing CWIS. However, there are notable uncertainties regarding the ability to implement this technology based on the above referenced flow characteristics within the existing CWIS, complex hydraulics and the resultant through-screen velocity. Further analysis, beyond the scope of this study, is required to validate the feasibility and determine the exact available increase in gross screen surface area that may be possible with dual-flow units.

Based upon observed entrained larvae at the LEC, the retention (exclusion) of larvae and eggs can be optimized by using a 0.5 mm mesh screen. The conceptual expansion of the CWIS in this study uses a 0.5 mm mesh screen and is being carried forward for further consideration.

All other technologies listed in the Rule are unreasonable, impractical or technically infeasible at the LEC.

10.12.1 Cost Summary

Table 10.22 lists the anticipated compliance cost for the three entrainment reduction technology alternatives deemed feasible at the LEC. The costs presented represent AACE Class 4 estimates based on the level of design and investigation as provided in this study. Entrainment reduction potential for each alternative will be studied in (r)(11). Non-water quality environmental and other impacts of these alternatives will be studied in (r)(12).

Table 10.22. Entrainment Compliance Cost Summary

	2.0 mm Fine Mesh Dual-Flow Conversion[1]	**0.5 mm Fine Mesh CWIS Expansion[1]**	**Closed-Cycle Cooling Towers**
Capital Cost	$19,500,000	$48,875,000	$431,900,000
30-Year O&M Cost (NPV)	$5,500,000	$9,700,000	$442,100,000
30-Year Total Project Cost (NPV)	$25,000,000	$58,575,000	$874,000,000

[1] Includes new traveling screens equipped with fish buckets, dual stage screen wash spray and a fish collection and return system.

10.13. REFERENCES

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11 40 CFR 122.21(r)(11) – BENEFITS VALUATION STUDY: ESTIMATES OF THE BIOLOGICAL AND ECONOMIC BENEFITS OF ENTRAINMENT REDUCTION TECHNOLOGY ALTERNATIVES

This section presents the estimates of the biological and economic benefits of reducing entrainment and impingement through the use of the following four intake entrainment BTA alternatives at the LEC based on the § 122.21(r)(10) study.

1. LEC cooling water pumps operating at the level observed during 2015 and 2016. This alternative serves as the baseline against which the other alternatives were compared.
2. LEC cooling water pumps operating at the level observed during 2015 and 2016 with the hypothetical installation of 2.0-mm fish-friendly fine-mesh traveling water screens in the existing intake structure coupled with a fish return system.
3. LEC cooling water pumps operating at the level observed during 2015 and 2016 with the hypothetical installation of an expanded intake structure with 0.5-mm fish-friendly fine-mesh traveling water screens coupled with a fish return system.
4. LEC cooling water pumps operating at the level observed during 2015 and 2016 with hypothetical conversion from once-through to closed-cycle cooling through the installation of wet cooling towers.

This section provides estimates of the equivalent fishery yield and economic value of fish entrained and impinged at the LEC cooling water intake as well as other environmental benefit considerations relative to entrainment and impingement losses. These benefits estimates can then be compared to the costs of various fish protection alternatives for § 316(b) compliance. Economic benefit estimating methods used in this study are consistent with those used by USEPA in their development of the § 316(b) Rule (USEPA 2014) and described in EPRI (2017).

11.1 ANNUAL ENTRAINMENT ESTIMATES AND TARGET SPECIES SELECTION

This following sub-sections provides an overview of the methods used to estimate annual entrainment that formed the basis for the economic valuation. In addition, these sub-sections briefly discuss the species of fish that were selected to be the basis for this valuation, referred to herein as "Target Species".

11.1.1 Available Entrainment and Impingement Data

Estimates of the annual entrainment and impingement that formed the basis for this assessment were developed from biological monitoring conducted during two years for entrainment and one year for impingement. Brief summaries of the methods and results of these studies are provided below.

11.1.2 Entrainment Sampling

Entrainment sampling was conducted at the LEC discharge seal well weekly from March through September in 2015 and 2016 to coincide with the period when entrainment of fish eggs and larvae was most likely to occur. Samples were collected approximately every 6 hours over each 24-hour sampling event to correspond with the following sampling time intervals: 0000-0600, 0600-1200, 1200-1800, and 1800-2400 hours. The sampling apparatus consisted of a pump-and-net barrel sampler fitted with a conical 335-micrometer mesh ichthyoplankton net to collect specimens and an inline flow meter to estimate the volume of water filtered. Sample water was withdrawn from the seal well through a 4-in. flex tube connected to a gasoline-powered trash pump and rigid 4-in. piping fixed to the sampling barrel. A minimum sample volume of 100 m^3 was targeted.

The 2015 study year was conducted over 30 sampling events from 3 March to 22 September, whereas the 2016 study year was conducted over 31 sampling events from 1 March to 27 September. Samples were collected during all planned time intervals and total volumes sampled during each event were consistent ranging from 406 to 428 m^3 across both study years. All samples collected were preserved in formalin and sent to the laboratory for processing.

In the laboratory, all fish eggs, larvae and juveniles were sorted from the sample and submitted for taxonomic analysis. If samples contained a large number of specimens or large amounts of detritus, samples were split using a Folsom plankton splitter. Sub-samples were then processed until a minimum of 200 specimens were found. Counts for individual sub-samples were maintained in the event that multiple sub-samples were required to reach a total of 200 specimens or in the event that an initial sub-sample containing more than 200 specimens was split a second time. The remainder of the sub-samples were also examined for the presence of potential endangered pallid sturgeon (*Scaphirhynchus albus*) specimens.

All taxonomic identifications were made by trained personnel familiar with native and non-native fish species in Missouri. Identifications were made to the lowest practical taxonomic level using a stereo- microscope with a polarized light set-up. Specimens were identified to stages of development, including egg, yolk-sac larva (YSL), post yolk-sac larva (PYSL), juvenile, and small adults. Larval specimens that could not be reliably assigned to a development stage were simply categorized as “larvae.” Up to 30 specimens per sample of each taxon and life stage (excluding eggs) were measured to the nearest 0.1 mm.

More details on the entrainment sampling procedures and laboratory analysis process for this study can be found in the LEC § 122.21(r)(9) Entrainment Characterization Study submittal.

11.1.3 Impingement Monitoring

Impingement monitoring is not explicitly required by the Rule. However, reductions in impingement mortality associated with each entrainment BTA alternative must be addressed as part of the Benefits Valuation Study. To meet this requirement, site-specific impingement data were evaluated from a one-year impingement monitoring program that was conducted biweekly (every other week) starting on 13 July 2005 and continuing until 13 July 2006. All scheduled sampling events were successfully completed except for 5 December 2005 when ice and debris clogged the impingement collection device and prevented sampling.

During each sampling event, a composite impingement sample was collected over a continuous 24-hr sampling period, generally commencing at approximately 0800 hour and continuing until approximately 0800 hour on the following day. Traveling water screens were rotated immediately prior to the start of the 24-hr collection to remove previously impinged fish and debris, and then were rotated as frequently as necessary during the collection period to maintain an acceptable head differential according to normal intake operating procedures. During periods of high debris loading, the screens were rotated on a more continual basis. At the conclusion of the 24-hr period the screens were rotated again to recover all impinged fish.

Impinged fish were collected in a specially constructed 4-ft x 4-ft x 4-ft metal frame basket with 3/8-in. woven mesh and ¼-in. nylon net liner, located beneath the floor where the screen wash water exits the screenhouse prior to being returned to the river. The collection basket was set and retrieved through an opening in the intake floor by the use of a jib crane. A sampling basket was kept in place throughout the 24-hr period to ensure that wash water would be continuously filtered. Impinged specimens collected during the screen washes were processed for species identification, length and weight measurements. More details on this impingement monitoring study are provided in ASA and ARL (2008).

11.1.4 Selection of Target Species

It is not practical or necessary to explicitly value all species entrained and impinged in an economic valuation study. Sufficient information does not exist to conduct the assessment for some species and many of the species found in entrainment and impingement monitoring are found in very small numbers. Therefore, economic assessments are typically conducted for a subset of Target Species. Target Species are most commonly selected to include contributors to all economic benefits categories, including recreational, and, where appropriate, commercial fishing, as well as forage species. In addition, ideally these Target Species should be representative of, and account for, a large portion of total annual entrainment and impingement at the facility being addressed. The results of the benefits valuation based on these Target Species can then be scaled up to reflect the benefits for all species entrained and impinged.

Based on a careful review of the available entrainment and impingement data for the LEC, four fish species or taxonomic groups were selected to be the focus of this economic valuation:

- Minnow family (Cyprinidae)
- Gizzard shad (*Dorosoma cepedianum*)
- Freshwater drum (*Aplodinotus grunniens*)
- Channel catfish (*Ictalurus punctatus*)

These four taxa were selected as they are representative of species typically entrained and impinged at the LEC and of each of the economic benefits categories as discussed above. In addition, sufficient information exists on each of these taxa for a technically-sound estimate of economic valuation

It was decided not to include Asian carps (a composite taxon including bighead (*Hypophthalmichthys nobilis*), silver carps (*Hypophthalmichthys molitrix*), and grass carp (*Ctenopharyngodon idella*)) as a Target Species despite the fact that this taxa accounts for more than 80 percent of entrainment at the LEC in recent years. Over the past few decades, Asian carps have invaded the Mississippi/ and Missouri river systems following accidental releases. Since that time, the abundances of these species have exploded, and these invasive species are now one of the more abundant fish species found in many parts of the system including the LMOR (Conover et. al., 2007). Despite their abundance in both the LEC entrainment and in the LMOR, they are not included in these benefits estimates for the following reasons:

1. They are not directly used by humans - Asian carps are not targeted by fishermen, hence there will be no direct use benefits. While plentiful, Asian carps are filter feeders and do not take bait or lures so there is no active recreational fishery. In addition, there is minimal commercial harvest as the markets for this taxon have not developed. In fact, resource

agencies have had to pay commercial fishermen to harvest them as part of population control measures.

2. <u>Adding more Asian carp to the LMOR will yield no indirect benefits</u> - Protecting Asian carp eggs and larvae from entrainment is directly analogous to adding more eggs and larvae of this taxon to the LMOR. In a well-balanced, fully functioning aquatic ecosystem, biomass produced is efficiently utilized to support ecosystem functions, including the growth and survival of desirable recreationally and commercially harvested species. Hence, in such efficient systems, adding more biomass of prey species can yield benefits to humans through improved fishing opportunities as the system is food limited as would be expected in the LMOR prior to the invasion of Asian carps.

   Since the Asian carp invasion, the LMOR can no longer be considered a well-balanced, fully functioning aquatic ecosystem, despite the fact that a number of fish predators consume young Asian carps. However, Asian carps grow quickly reaching more than a foot long within a year; a size few predators can consume. Consequently, for much of their life, Asian carps have few effective predators in the LMOR to keep these species in check. For these two reasons, it is unlikely that protecting Asian carp from loss through entrainment will yield any improvements to fishing opportunities through greater growth or survival of harvested species.

3. <u>Asian carps have negative consequences</u> - While the effects of this invasion on the indigenous fish community and on the overall ecosystem health in the LMOR have not been well studied, studies conducted in other areas, including the adjacent Mississippi and Illinois Rivers, suggest that significant and profound effects on ecosystem structure and function have occurred including

   Competition with Native Species: Sampson et al. (2009) found a high degree of dietary overlap between Asian carps and two native planktivorous species, gizzard shad and bigmouth buffalo (*Ictiobus cyprinellus*) in the Mississippi and Illinois rivers. Historically, these two species were highly abundant species in the LMOR. Subsequently, Pendleton et al. (2017) report statistically significant declines in condition and abundance of these two species in the Illinois River coincident with the Asian carp invasion. The authors attributed these effects to competition for planktonic food resources. Likewise, declines in fish diversity, reproductive success, population abundance and condition factors have been associated with Asian carp introductions in other systems as reported by Cudmore et al. (2012). Again, heavy predation on plankton populations and outcompeting native planktivores was reported as the likely cause.

   Food Web Alteration: Sass et. al. (2014) documented significant changes in the zooplankton community abundance and composition in the Illinois River following the invasion by Asian carps. In this study, the abundance of copepods and cladocerans decreased while the abundance of rotifers, the preferred food of Asian carps, increased following establishment of Asian carps in this river. The authors suggested that such changes in the zooplankton community could be beneficial to Asian carps but detrimental to native fish species.

Further, intensive predation on planktonic resources by Asian carps resulted in reductions in filamentous algae and zooplankton in an experimental pond system (Collins and Wahl 2017). In this experiment, inefficient conversion of food into fish tissue by Asian carps led to a large portion of consumed materials being shunted from the pelagic to benthic habitats with a potential for substantial consequences to ecosystem food webs.

Direct Predation: Further, Asian carps have the potential to directly prey on zooplankton and fish eggs and larvae through their filter-feeding activities (Zhang et al. 2016). To the extent this occurs, significant effects on the recruitment of other species, including mussels and important recreational fish, could occur (Zhang et al. 2016).

Direct Effects on Humans: The explosion of the Asian carp populations throughout the Mississippi River Basin, including the LMOR, have increased direct impacts to human through injury and death. Asian carps (esp. silver carp) are known to leap out of the water, possibly injuring water-skiers or landing in boats causing damage to property and injuries to boaters (Chapman 2010).

It is for all the above listed negative impacts that numerous governmental agencies have substantial programs to actively control and reduce its abundance over its current range and to prevent their further spread throughout the United States and Canada (ACRCC 2018). Based on the above, it is clear that protection of Asian carp eggs and larvae from entrainment will have little or no benefits to fishermen and will, in fact, likely exacerbate the negative consequences of this nuisance species in the LMOR[1].

Together, the four Target Species accounted for 35.2 – 43.9 percent of total annual non-Asian carp entrainment and 94.5 percent of non-Asian carp impingement at the LEC. No threatened or endangered species were collected in either entrainment or impingement monitoring at the LEC (LEC 122.21(r)(9) Entrainment Characterization Study Report, ASA and ARL 2008).

11.1.5 Estimation of Annual Entrainment and Impingement

The results of the entrainment and impingement monitoring programs described above were used to calculate the total annual loss of fish eggs and larvae at the LEC for each study. These losses were calculated using water withdrawal rates estimated for 2015 and 2016. In addition, estimates of annual entrainment and impingement were calculated using the various intake alternatives listed at the beginning of Section 11.

[1] Note: For the same reasons discussed above, the State of Nebraska has designated Asian carp as a nuisance species and, hence, not subject to BTA protection under 40 CFR 125.92(b) (Letter from S.M. Goans, Nebraska Department of Environment and Energy, to M. Krumland, Nebraska Public Power District dated August 2, 2019).

11.1.5.1 Annual Entrainment

Annual estimates of entrainment mortality were calculated for each alternative for each life stage (l) of each target species (s) as follows:

$$Annual\ entrainment = \sum_{i=1}^{365}\sum_{p=1}^{4} d_{islp} \times V_{ip} \times [(1 - E_{sl}) + (E_{sl}\ \times\ (1 - S_{sl}))]$$

where:

d_{islp} = Mean density of species (s) and life stage (l) entrained on day (i) during sampling period (p);
E_{sl} = Fraction excluded for species (s) and life stage (l);
V_{ip} = Total water withdrawal volume on day (i) during period (p); and,
S_{sl} = Mean fraction of species (s) and life stage (l) surviving exclusion.

No survival of entrained organisms was assumed.

Daily Entrainment Densities

Mean daily densities were obtained or calculated from the individual sample densities from the 2015 and 2016 entrainment monitoring studies at the LEC for each sampling event, Target Species and age/life stage. These densities were assumed to reflect the mean densities for the entire period extending from one-half the time from the previous sampling event to one-half the time to the subsequent sampling event.

Cooling Water System Operations

Water withdrawal rates used for the baseline and fine-mesh traveling water screen cases were assumed to be the same as actually measured at the LEC in 2015 and 2016, respectively. Makeup water for a closed-cycle cooling tower installation was assumed to come from new collector wells to be developed onsite. Hence, under this alternative, there will no longer be any withdrawal of cooling water from the Missouri River (LEC § 122.21(r)(10) Technology Feasibility Study).

Screen Exclusion and Mortality

Several of the intake technologies proposed to reduce entrainment by employing fine-mesh traveling water screens to exclude fish eggs and larvae from cooling water flow as it enters the screenhouses at the LEC. In order to determine the effectiveness of these screening technologies, estimates of screening efficiency and resulting mortality of those individuals excluded as a result from subsequent impingement on the fine-mesh traveling water screens are needed. As both screen exclusion and fine-mesh impingement mortality are a function of the size of the individuals entrained coupled with dimensions of the mesh, estimates of screen exclusion were developed taking into account the likely length ranges of each species entrained at LEC using information provided in Appendix 11 A. Estimates of the survival of impingeable-sized fish are also provided in Appendix 11 A.

11.1.5.2 Annual Impingement

Annual estimates of impingement were calculated for each alternative and Target Species (s) as follows:

$$Annual\ impingement\ loss = \sum_{i=1}^{365} d_{si} \times V_i \times [\ (1 - S_{is})\ \times\ (1 - RF)\ ]$$

where:

d_{si} = Mean density of species (s) impinged on day (i);
V_i = Total water withdrawal volume on day (i);
S_{is} = Mean fraction of species (s) surviving impingement during day (i) for each alternative; and,
RF = Reduction in cooling water flow for each alternative.

Sources for the inputs to the above calculations are described below.

Impingement Densities

Mean daily impingement densities were calculated for each sampling event, species and life stage from a one-year impingement monitoring study at the LEC. These densities were assumed to reflect the mean densities for the entire period extending from one-half the time from the previous sampling event to one-half the time to the subsequent sampling event.

Impingement Survival

For the baseline, it was assumed that all fish impinged died (i.e., no impingement survival). For the fine-mesh traveling water screens, impingement survival was used as described in Appendix 11 A.

Cooling Water System Operations

Water withdrawal rates used for the baseline and fine-mesh traveling water screen cases were assumed to be the same as actually measured at the LEC in 2015 and 2016, respectively. Makeup water for a closed-cycle cooling tower installation was assumed to come from new collector wells to be developed onsite. Hence, under this alternative, there will no longer be any withdrawal of cooling water from the Missouri River (LEC § 122.21(r)(10) Technology Feasibility Study).

11.1.5.3 Assignment of Age Categories for Impinged Individuals

One of the necessities of equivalent loss calculation is that the direct measures of impingement mortality must be assigned to individual age categories as defined in the production foregone and equivalent yield models. For this assessment, age was assigned using length information for each Target Species obtained from impingement monitoring conducted at the LEC, together with estimates of maximum length at age for these same species obtained from the scientific literature and from an analysis of the length-frequency patterns for each species. The upper length limits used to designate each age group are provided in the Table 11-1.

Table 11-1 Upper length limits by age group for target species.

Age	Upper size limits (mm) for age class			
	Channel catfish	Freshwater drum	Gizzard shad	Minnows
0	170	187	165	40
1	259	263	235	64
2	337	317	280	89
3	402	361	320	99
4	461	397	355	103
5	519	427	385	
6	566	452	>385	
7	590	483		
8	>590	513		
9		540		
10		563		
11		580		
12		>580		

11.1.6 Estimated Annual Losses

Estimates of the annual non-Asian carp entrainment losses under baseline conditions and each of the intake alternatives are provided for each Target Species in Table 11-2 and Table 11-3. Total entrainment based on 2015 and those based on 2016 were comparable. In both study years, entrainment was dominated by minnows (principally larvae) which accounted for 52 to 69 percent of baseline non-Asian carp entrainment.

Estimates of the annual impingement losses under baseline conditions and each of the intake alternatives are provided for each Target Species in Table 11-4 and Table 11-5. These estimates are based on biological sampling over a single year (2005) but using two years of facility operational information. As a result, impingement losses were comparable between the years and impingement was dominated by gizzard shad which accounted for more than 70 percent of baseline impingement.

Table 11-2 Estimated annual entrainment losses (in millions) by Target Species and technology alternative at the LEC using entrainment data from 2015 and actual flow data from that same year.

Study Year = 2015/Flow Year = 2015					
Target Species	Stage[a]	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	Egg	0.00	0.00	0.00	0.00
	YSL	0.00	0.00	0.00	0.00
	PYSL	0.28	0.15	0.14	0.00
	Juv	0.29	0.05	0.05	0.00
	All	0.57	0.20	0.20	0.00
Freshwater drum	Egg	11.59	11.59	4.29	0.00
	YSL	0.00	0.00	0.00	0.00
	PYSL	46.81	46.35	45.52	0.00
	Juv	0.21	0.00	0.00	0.00
	All	58.61	57.95	49.81	0.00
Gizzard shad	Egg	0.00	0.00	0.00	0.00
	YSL	0.00	0.00	0.00	0.00
	PYSL	100.10	99.78	99.13	0.00
	Juv	5.12	2.49	2.48	0.00
	All	105.21	102.27	101.61	0.00
Minnows	Egg	0.00	0.00	0.00	0.00
	YSL	0.90	0.90	0.78	0.00
	PYSL	180.79	180.79	128.67	0.00
	Juv	0.00	0.00	0.00	0.00
	All	181.69	181.69	129.46	0.00
Total Targets	All	346.08	342.10	281.07	0.00

[a] Egg = Egg stage; YSL = Yolk-sac larvae; PYSL = Post yolk-sac larvae; Juv = Entrainable juvenile stage; and, All = All stages combined.

Table 11-3 Estimated annual entrainment losses (in millions) by Target Species and technology alternative at the LEC using entrainment data from 2016 and actual flow data from that same year.

Study Year = 2016/Flow Year = 2016					
Target Species	**Stage[a]**	**Baseline**	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	Egg	0.00	0.00	0.00	0.00
	YSL	0.00	0.00	0.00	0.00
	PYSL	0.00	0.00	0.00	0.00
	Juv	0.09	0.02	0.02	0.00
	All	0.09	0.02	0.02	0.00
Freshwater drum	Egg	3.27	3.27	1.21	0.00
	YSL	50.66	50.66	49.36	0.00
	PYSL	33.61	33.29	32.69	0.00
	Juv	0.09	0.00	0.00	0.00
	All	87.63	87.21	83.26	0.00
Gizzard shad	Egg	0.00	0.00	0.00	0.00
	YSL	0.00	0.00	0.00	0.00
	PYSL	10.94	10.91	10.84	0.00
	Juv	0.94	0.46	0.46	0.00
	All	11.89	11.37	11.30	0.00
Minnows	Egg	0.00	0.00	0.00	0.00
	YSL	0.10	0.10	0.08	0.00
	PYSL	219.51	219.51	156.23	0.00
	Juv	0.00	0.00	0.00	0.00
	All	219.61	219.61	156.32	0.00
Total Targets	All	319.22	318.21	250.89	0.00

[a] Egg = Egg stage; YSL = Yolk-sac larvae; PYSL = Post yolk-sac larvae; Juv = Entrainable juvenile stage; and, All = All stages combined.

Table 11-4 Estimated annual impingement losses by Target Species and technology alternative at the LEC using impingement data from 2005 and actual flows from 2015.

Study Year = 2005/Flow Year = 2015				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	46,635	8,674	8,674	0
Freshwater drum	722,415	349,649	349,649	0
Gizzard shad	1,966,996	952,026	952,026	0
Minnows	5,131	1,098	1,098	0
Total	2,741,178	1,311,447	1,311,447	0

Table 11-5 Estimated annual impingement losses by Target Species and technology alternative at LEC using impingement data from 2005 and actual flows from 2016.

Study Year = 2005/Flow Year = 2016				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	42,187	7,847	7,847	0
Freshwater drum	677,892	328,099	328,099	0
Gizzard shad	1,786,205	864,523	864,523	0
Minnows	4,633	991	991	0
Total	2,510,917	1,201,461	1,201,461	0

11.2 ESTIMATES OF BIOLOGICAL BENEFITS

To calculate economic value of entrainment and impingement losses at the LEC, estimates of the number of individuals entrained for each of the Target Species must be converted to equivalent measures that can be assigned economic value for these species. For species of commercial and/or recreational importance, the equivalent measure selected was the yield to the fishery that would have been expected had the individuals not been entrained or impinged. For species that serve as forage for other, generally larger, aquatic organisms, the measure selected was the production of biomass available as food for higher trophic levels that would have been expected had the individuals not been entrained or impinged. Methods used in this study to calculate these two measures are consistent with those used by USEPA in the most recent § 316(b) rulemaking effort (USEPA 2014) and are described below.

11.2.1 Equivalent Fishery Yield

The measure "yield to the fishery" for Target Species of commercial and/or recreational importance is defined as the total yield (in weight) that could have occurred in the commercial or recreational fishery from those individuals lost to entrainment or impingement in the absence of compensatory changes in total mortality. This yield is calculated using the Equivalent Yield Model (EYM), which integrates Baranov's catch equation (Ricker 1975) with estimates of the mean weight by age (Dey 2002, EPRI 2004a). This method is conservative in that potential density-dependent changes in mortality or growth rates that often occur in natural populations were not included. Using the EYM, equivalent yield (EY) for each alternative and Target Species of commercial and/or recreational importance from entrainment or impingement was estimated as follows:

$$EFY = \sum_{i=1}^{nf} \left[\sum_{j=1}^{n_l} \left(NL_j S_{j \to i} \right) A_i W_i \frac{V_i F_i}{Z_i} \right]$$

where:

EFY	=	Equivalent yield to fishery;
nf	=	Maximum number of Stage or Age categories vulnerable to fishery;
n_j	=	Number of Stages or Age Categories (j) entrained or impinged at LEC;
NL_j	=	Number of each Stage or Age Category (j) lost to entrainment or impingement at LEC;
$S_{j\to i}$	=	Total survival from Stage or Age Category (j) to Age (i);
A_i	=	Total mortality rate for Stage or Age Category (i) = $1\text{-}e^{-Z_i}$;
W_i	=	Average weight for individual of Stage or Age Category (i) captured in the fishery;
V_i	=	Fraction of Stage or Age Category (i) vulnerable to fishing;
F_i	=	Instantaneous fishing mortality rate for Stage or Age Category (i); and,
Z_i	=	Instantaneous total mortality rate for Stage or Age Category (i).

The EYM results in an estimate of equivalent yield defined in the same units used to describe the average weight of the individuals and integrates yield across all ages. In this assessment, the EYM was applied to channel catfish and freshwater drum as these are the Target Species which support local fishing.

11.2.2 Biomass Production Foregone

The measure of biomass production that could have resulted from all Target Species entrained or impinged at the LEC was calculated using the Production Foregone Model (PFM) (Dey 2002, EPRI 2004a). As with the EYM, this method is also conservative in that potential density-dependent changes in mortality or growth rates that often occur in natural populations were not included. Using the PFM, potential biomass production from entrainment or impingement was estimated for each of alternative and Target Species as follows:

$$P_i = \sum_{i=1}^{L} \frac{\sum_{j=1}^{n_l} \left(NL_j S_{j\rightarrow i}\right) G_i W_i \left(e^{(G_i - Z_i)} - 1\right)}{G_i - Z_i}$$

where:

P_i	=	Production foregone for individuals entrained or impinged at LEC in Stage or Age Category (i);
L	=	Final age category;
N_j	=	Number of Stages or Age categories entrained or impinged at LEC;
NL_j	=	Number of each Stage or Age Category (j) lost to entrainment or impingement at LEC;
$S_{j\rightarrow i}$	=	Total survival from Stage or Age Category (j) to Age (i);
G_i	=	Instantaneous growth rate in weight for Stage or Age Category (i);
W_i	=	Average weight of individuals in Stage or Age Category (i); and,
Z_i	=	Instantaneous mortality rate for Life Stage or Age Category (i).

The total production foregone (P) can be found by summing over all the age categories that are entrained or impinged at LEC:

$$P = \sum_{i=1}^{m} P_i$$

where:

m	=	Total number of age categories for each Target Species.

The PFM was applied to <u>all</u> Target Species as all would serve as food for other aquatic organisms during at least part of their life cycle.

Additionally, relationships among the key inputs to the EYM and PFM are as follows:

$$Z_i = M_i + F_i$$
$$A_i = 1 - e^{-Z_i}$$
$$S_{j \to i} = 1 - \prod_{i=j}^{r} (1 - A_i)$$
$$G_i = \ln\left(\frac{BW_{i+1}}{BW_i}\right)$$
$$W_i = BW_i e^{G_i \bar{T}_i}$$

where:

M_i	=	Instantaneous natural mortality rate for Stage or Age Category (i);
BW_i	=	Average weight of individuals at the beginning of Stage or Age Category (i);
BW_{i+1}	=	Average weight of individuals at the beginning of Stage or Age Category (i+1);
$S_{j \to i}$	=	Total survival from Stage or Age Category (j) to Age (i);
r	=	Total number of age categories between Age Category (j) and Age Category (i);
$\bar{T}_i$	=	Median fraction of Stage or Age Category (i) completed $= \frac{\ln(2) - \ln(1 + e^{-Z_i t_i})}{Z_i}$; and,
t_i	=	Duration of Stage or Age Category (i).

More information on these inputs and relationships can be found in Ricker (1975). Estimation of the biological input parameters for each of the Target Species is described below.

This category includes benefits that accrue to humans from the use of the resource indirectly. Relative to § 316(b) regulations, the indirect benefit that could result from reductions in entrainment or impingement would be through an increased consumption by higher trophic levels of production that results from these organisms. This increased consumption could result in greater growth and survival rates among fish in higher trophic levels, and, hence, increase fishing opportunities. Production consumed by higher trophic levels results from both forage species, such as gizzard shad, as well as individuals of harvested species that die of natural causes.

11.2.3 Trophic Transfer of Biomass Foregone

Unfortunately, there are no generally accepted methods to directly assign a value to this benefit. Instead, the value of this benefit is assigned indirectly by quantifying the amount of commercially and/or recreationally important species that could be supported by the production potentially generated by these entrained and impinged organisms, which were subsequently harvested by man. Hence, the value of the production increase resulting from implementation of any entrainment reduction efforts is equal to the value of the increase in commercial and/or recreational harvest that could be supported by that production.

The value of the indirect benefits was estimated for the Target Species entrained and impinged at LEC using the following two-step process.

Step 1 – Estimation of Total Biomass of Higher Trophic Levels Supportable by the Annual Productivity Equivalent to the Reduction in Entrainment or Impingement. The total biomass of higher trophic levels supportable is calculated by using a trophic transfer method as follows:

$$HTB = \sum_{S=1}^{n} \left(PFB_S\right) \times TTC$$

where:

HTB = Total annual higher trophic level biomass (lb) supported by production foregone attributable to entrainment or impingement;
PFB_S = Biomass production foregone for Target Species (S) attributable to entrainment and impingement;
n = Number of Target Species; and,
TTC = Trophic transfer coefficient.

This approach is identical to that used by USEPA in the § 316(b) Final Existing Facilities Rule (USEPA 2014).

For this assessment, production foregone estimates from entrainment and impingement for each of the Target Species were calculated using the PFM as described in Section 11.2.2. These estimates of production foregone were based on estimates of annual entrainment and impingement at the LEC. A trophic transfer coefficient of 10 percent, which is consistent with USEPA (2014), was then used to convert the total biomass foregone to an amount of higher trophic level biomass supportable by that production foregone for each of the Target Species. The coefficient means that an average of 10 percent of the production foregone would have ended up as predator biomass. For the uncertainty analysis, a range for the trophic transfer coefficient of 5 to 15 percent was assumed.

Step 2 – Estimation of Fishery Harvest Supported by Annual Productivity Equivalent to the Annual Entrainment and Impingement. As previously noted, the value of indirect benefits is determined by the value of the commercial and/or recreational harvest supported by the increased productivity. Hence, the total higher trophic level biomass estimated under Step 1 needs to be converted to an estimate of actual yield to the fishery expressed as equivalent predator harvest. This is accomplished by assuming that the total higher-level biomass is converted to biomass of a popular commercial or recreational species and then multiplying the value by the annual fishery exploitation rate for that species as follows:

$$EPY = HTB \times ER_{EP}$$

where:

EPY = Equivalent predatory yield (lbs) attributable to entrainment or impingement;
HTB = Higher trophic level biomass (lbs) attributable to entrainment or impingement; and,
ER_{EP} = Fishery exploitation rate for the selected equivalent predator.

For this assessment, the equivalent predator was assumed to be channel catfish, the most popular target of recreational fishermen in the LMOR (MDOC 2011). In reality, any potential production increase would of course be transferred among many species, including some with little or no recreational importance. Therefore, this species should be a conservative species for assigning economic value for this assessment. The annual exploitation rate for the equivalent predator was assumed to be moderate (15 percent). For the uncertainty analysis, a range of 10 to 20 percent was assumed.

11.2.4 Biological Inputs

Biological input parameters for the Production Foregone and Equivalent Yield models include life stage durations, instantaneous natural and fishing mortality rates, and the fraction vulnerable to the fishery for each life stage and age, as well as mean weights at the beginning of each life stage and age for each Target Species. Values for each of these parameters for the four Target Species used in this study are provided in Appendix 11 B. For the most part, these values were derived from EPRI (2012). Exceptions are noted as footnotes on each species table. To increase precision in the estimates of equivalent loss, calculations for Ages 0+ through 4+ were made on a monthly basis. Hence, values for each life history parameter except weights were assumed to be constant across each age. Mean weights at the beginning of each month were interpolated by assuming a constant instantaneous growth rate for each age.

These population parameters were adjusted, where necessary to reflect a stable population, (i.e., one that is neither increasing nor decreasing). Methods used to make these adjustments are described in Appendix 11 C. While in any particular year or set of years a population can increase or decrease from a variety of factors, a stable population must be the long-term average for a population to persist and, hence, is a sound basis for benefits valuation over the long term.

11.2.5 Biological Benefits

The biological benefits measure the biological improvements to the source waterbody as a result of installation of each potential BTA technology. In this case, the biological benefits are the predicted increases in annual fishery yield. These increases are the differences between the equivalent fishery yield for each Target Species and the Equivalent Predatory Yield calculated under the Baseline Case and the equivalent fishery yield calculated for each potential BTA alternative.

11.2.6 Results

Equivalent loss estimates, defined in terms of equivalent fishery yield and production foregone, are the primary biological input to the economic valuation. Annual fishery yields equivalent to each of the Target Species entrained and impinged are provided in Table 11-6 and Table 11-7, respectively. The biological benefit of each potential intake alternative is the difference between the lost fishery yield of entrainment or impingement under current operation and that expected loss with the operation of each alternative.

Annual biomass production foregone equivalent to each of the Target Species entrained or impinged are provided in Table 11-8 and Table 11-9, respectively. The indirect biological benefit of each potential intake alternative is the difference between the production foregone of entrainment or impingement under actual operation and that expected with the operation of each alternative.

Biological benefits, defined in terms of increased fishery yield, associated with each intake technology are provided in Table 11-10, Table 11-11, and Table 11-12 for entrainment, impingement and entrainment and impingement combined, respectively.

Table 11-6 Estimated annual equivalent fishery yield (in pounds) by Target Species and technology alternative at the LEC using entrainment data by study year.

Study Year = 2015/Flow Year = 2015				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	1,931	553	545	0
Freshwater drum	15,271	12,747	12,511	0
Gizzard shad	0	0	0	0
Minnows	0	0	0	0
Total	17,201	13,301	13,056	0
Study Year = 2016/Flow Year = 2016				
Target Species	**Baseline**	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	428	80	80	0
Freshwater drum	10,514	9,340	9,168	0
Gizzard shad	0	0	0	0
Minnows	0	0	0	0
Total	10,941	9,420	9,248	0

Table 11-7 Estimated annual equivalent fishery yield (in pounds) by Target Species and technology alternative at the LEC using impingement data by study year.

Study Year = 2005/Flow Year = 2015				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	1,833	341	341	0
Freshwater drum	21,698	10,502	10,502	0
Gizzard shad	0	0	0	0
Minnows	0	0	0	0
Total	23,531	10,843	10,843	0
Study Year = 2005/Flow Year = 2016				
Target Species	**Baseline**	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	1,558	290	290	0
Freshwater drum	20,222	9,787	9,787	0
Gizzard shad	0	0	0	0
Minnows	0	0	0	0
Total	21,780	10,077	10,077	0

Table 11-8 Estimated annual production foregone (in pounds) by Target Species and technology alternative at the LEC using entrainment data by study year.

Study Year = 2015/Flow Year = 2015				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	4,212	1,208	1,190	0
Freshwater drum	115,318	96,347	94,562	0
Gizzard shad	135,281	96,790	96,211	0
Minnows	46,487	46,487	33,100	0
Total	301,297	240,833	225,063	0
Study Year = 2016/Flow Year = 2016				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	931	174	173	0
Freshwater drum	79,443	70,616	69,320	0
Gizzard shad	20,380	13,302	13,224	0
Minnows	56,346	56,346	40,104	0
Total	157,100	140,438	122,822	0

Table 11-9 Estimated annual production foregone (in pounds) by Target Species and technology alternative at the LEC using impingement data by study year.

Study Year = 2005/Flow Year = 2015				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	3,649	679	679	0
Freshwater drum	134,216	64,960	64,960	0
Gizzard shad	146,604	70,956	70,956	0
Minnows	9	2	2	0
Total	284,476	136,597	136,597	0
Study Year = 2005/Flow Year = 2016				
Target Species	Baseline	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	3,129	582	582	0
Freshwater drum	125,091	60,544	60,544	0
Gizzard shad	130,479	63,152	63,152	0
Minnows	8	2	2	0
Total	258,707	124,279	124,279	0

Table 11-10 Estimated annual biological benefits defined as increased fishery harvest[a] (lbs) from entrainment by Target Species and Alternative at the LEC across two study and two flow years.

Study Year = 2015/Flow Year = 2015			
Target Species	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	1,377	1,386	1,931
Freshwater drum	2,524	2,760	15,271
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[b]	907	1,144	4,519
Total	4,808	5,289	21,721
Study Year = 2016/Flow Year = 2016			
Target Species	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	348	348	428
Freshwater drum	1,174	1,345	10,514
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[b]	250	514	2,357
Total	1,772	2,208	13,298

[a] Includes harvest by both commercial and recreational fishermen. Does not include benefits from increased recreational catch that are released.
[b] Equivalent predator set to channel catfish.

Table 11-11 Estimated annual biological benefits defined as increased fishery harvest[a] (lbs) from impingement by Target Species and Alternative at the LEC across two study and two flow years.

Study Year = 2005/Flow Year = 2015			
Target Species	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	1,492	1,492	1,833
Freshwater drum	11,196	11,196	21,698
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[b]	2,218	2,218	4,267
Total	14,906	14,906	27,798
Study Year = 2005/Flow Year = 2016			
Target Species	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	1,268	1,268	1,558
Freshwater drum	10,434	10,434	20,222
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[b]	2,016	2,016	3,881
Total	13,719	13,719	25,661

[a] Includes harvest by both commercial and recreational fishermen. Does not include benefits from increased recreational catch that are released.
[b] Equivalent predator set to channel catfish.

Table 11-12 Estimated annual biological benefits defined as increased fishery harvest[a] (lbs) from entrainment and impingement combined by Target Species and Alternative at the LEC across two study and two flow years.

Study Year = 2015-2005/Flow Year = 2015			
Target Species	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	2,869	2,878	3,764
Freshwater drum	13,720	13,956	36,969
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[b]	3,125	3,362	8,787
Total	19,714	20,195	49,519
Study Year = 2016-2006/Flow Year = 2016			
Target Species	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	1,616	1,616	1,986
Freshwater drum	11,609	11,780	30,736
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[b]	2,266	2,531	6,237
Total	15,491	15,927	38,959

[a] Includes harvest by both commercial and recreational fishermen. Does not include benefits from increased recreational catch that are released.
[b] Equivalent predator set to channel catfish.

11.3 ECONOMIC BENEFITS

11.3.1 Annual Economic Benefits

In the most recent § 316(b) rulemaking, USEPA defines "economic benefits" under § 316(b) as the dollar value associated with environmental changes that enhance the welfare of individual humans resulting from the implementation of an alternative intake structure fish protection technology (USEPA 2014). In this assessment, the economic benefits associated with each alternative were calculated by assuming that the economic value of fish entrained or impinged is equivalent to the total economic benefit that could accrue to the public, had they not been entrained or impinged under that alternative.

USEPA defines methods for measuring four categories of economic benefits relevant to § 316(b) regulations for existing facilities: market direct use benefits, non-market direct use benefits, indirect use benefits, and non-use benefits. The value of marketed goods is equivalent to the sum of predicted changes in "consumer and producer surplus". Producer surplus is the difference between the price obtained for a good (e.g., fish) and the cost of producing that commodity. Consumer surplus is the difference between the perceived value of a good or service to the consumer and the cost of acquiring that good or service. Non-marketed goods, such as recreational fishing, normally require using indirect markets, such as travel and the cost of fishing gear, to infer their value. Indirect use benefits refer to increases in direct use benefits that might result indirectly such as through increases in forage fish abundance even though the resources themselves are not directly used. Finally, in addition to these direct and indirect use-related values, there is a potential for environmental changes to increase the welfare of individuals who do not use the resource at all. These latter benefits are considered non-use benefits. More details on the economic value categories and the estimation process used are provided in EPRI (2017)

11.3.1.1 Methods

The potential economic benefits of entrainment or impingement at the LEC were calculated for each of the benefit categories described using standard economic concepts outlined in USEPA (2014). Each of these benefit categories are discussed in detail below.

Direct Use Benefits

Direct use benefits accrue to those individuals that directly use the aquatic resources affected; in other words, commercial and recreational fishermen. The economic value of this benefit category is then equivalent to the economic value of the increased harvest by fishermen that would result had the fish not been entrained or impinged. Estimates of this increased harvest are equal to the biological benefit defined as equivalent fishery yield as described in the previous section and listed in Table 11-10, Table 11-11 , and Table 11-12. These biological benefit values were defined in terms of pounds to be consistent with reported fishery economic statistics. Using these estimates of increased fishery harvest, the economic value of the direct use benefit category was estimated for each sub-component (market and nonmarket) as follows:

Market Benefits (Commercial Fishing)
Market benefits refer to economic benefits that can be directly measured from data obtained in the marketplace. Changes in the magnitude of commercial fish and shellfish harvests are the principal market benefits relevant to § 316(b) regulations. Since reductions in entrainment and

impingement losses at cooling water intake structures have the potential to increase stock size, and hence commercial harvests, positive market benefits could potentially accrue from compliance with § 316(b) regulations. These market benefits represent the increase in profits to commercial fishermen that could result from any increase in harvest. Market benefits were calculated as follows:

$$CFB_S = EFY_S \times CP_S \times FC_S \times PS$$

where:

CFB_S = Economic benefit ($) to commercial fishing for each Target Species (S);
EFY_S = Equivalent fishery yield (lbs) for each Target Species (S);
CP_S = Dockside price per pound paid to commercial fishermen for Target Species (S);
FC_S = Fraction of the total fishery yield harvested by commercial fishermen for Target Species (S); and,
PS = Producer surplus (fraction of total harvest revenue retained by commercial fishermen).

Estimates of the annual dockside landings and value in the upper Mississippi River Basin for channel catfish and freshwater drum for the five-year period 2001 - 2005 were obtained from USACE (2012). The total value was then divided by the total landings to determine the average dockside price per pound for channel catfish and freshwater drum, the two Target Species most commonly harvested by commercial fishermen. These reported values were inflated to 2018 values using the Consumer Price Index (CPI) and were used as the most probable value. Maximum and minimum values used in the uncertainty analysis for each species were assumed to be 25 percent higher and lower than the most probable value, respectively. The resulting commercial values used in this assessment are provided in Table 11-13.

Table 11-13 Commercial values for Channel catfish and Freshwater drum

Target Species Subject to Commercial Harvest	Commercial Value (2018 $/lb)		
	Minimum	Most Probable	Maximum
Channel catfish	0.51	0.69	0.86
Freshwater drum	0.13	0.18	0.22

These dockside values, however, represent only the revenue returned to commercial fishermen and not the economic benefit (i.e., profits) of these fish. To estimate commercial fishing profits, the estimates of revenue need to be adjusted by both the consumer and the producer surplus rates. As assumed in USEPA (2014), we assumed that the levels of entrainment and impingement, if eliminated, would yield no consumer surplus. While there are many methods that can be used to estimate producer surplus, USEPA (2014) provided a range of estimates defined as a fraction of revenue based on a review of relevant studies for the Inland region. Using these values, a most probable value of 29 percent and the minimum and maximum of 22 and 39 percent, respectively, were the highest and lowest values reported for commercially-harvested species in this assessment.

Finally, the maximum, minimum, and most probable estimates for the fraction of the total fishery harvest attributable to commercial fishing was developed using best professional judgement as there is little empirical data to develop reliable estimates. Reported annual landings of channel catfish and freshwater drum in the Missouri River (MDOC Undated) have been very low compared to expected recreational harvest. Given these relatively low harvest commercial rates we conservatively assumed 10 percent of both Target Species were harvested by commercial fishing with a range of 0 to 20 percent for the uncertainty analysis.

Non-Market Direct Use Values (Recreational Fishing)

Harvested Fish

Non-market direct use benefits are those through the use of the resource that are not reflected in the market for the resource. Relative to § 316(b) regulations, the most common benefit that would accrue from reductions in entrainment and impingement would be through increases in recreational fishing opportunities. Increased abundance of adult fish that could result from decreasing entrainment or impingement losses could lead to increased catch rates for individual fisherman as well as an increase in the number of fishing trips by fishermen.

Unfortunately, economic value of increased recreational use of the resource is not directly reflected in the primary market. However, USEPA concluded that there is considerable literature to support valuing this benefit through estimation of a fisherman's "willingness to pay" for recreational opportunities. Thus, the non-market direct use benefit for additional recreational catch can be defined as the increase in the total "willingness to pay" across all fishermen resulting from the potential greater recreational opportunities due to reduction in entrainment or impingement losses. The recreational values used represent the marginal benefit per unit change in recreational catch.

For this assessment, total "willingness to pay" for each Target Species harvested by recreational fishermen was calculated by multiplying the estimated equivalent fishery yield to the recreational fishermen by the expected value per pound that recreational fishermen were willing to pay for an increased harvest:

$$RHFB_S = EFY_S \times RP_S \times (1 - FC_S)$$

where:

$RHFB_S$ = Economic value ($) to recreational harvest fishing for each Target Species (S);
EFY_S = Equivalent fishery yield (lbs) for each Target Species (S);
RP_S = Value per pound recreational fishermen are willing to pay for the increase in harvest of the Target Species (S); and,
FC_S = Fraction of the total fishery yield harvested by commercial fishermen for Target Species (S).

The equivalent yield to the recreational fishery at the LEC (Table 11-2) appears to be only a very small fraction of the likely recreational catch of comparable species in the LMOR. Hence, there is no reason to expect that changes in recreational fishing harvest that might result from reductions in entrainment or impingement at the facility will be sufficiently large so as to affect the price the fishermen are willing to pay. Therefore, it is assumed that the values the recreational fishermen are currently willing to pay for each species should be a reasonable measure of the value they would be willing to pay had entrainment or impingement not occurred. This is the same assumption used by USEPA in calculating the national benefits of the § 316(b) Rule (USEPA 2014).

For this assessment, the values provided in USEPA (2006 Table A7-3 for the Inland Region) were used to assign the recreational value per fish for each of only two Target Species supporting recreational fishing, channel catfish and freshwater drum. The maximum and minimum values were assumed to be represented by the upper and lower 95th percent confidence bounds (USEPA 2006 Table A7-4). Both Target Species were assigned panfish values. Values presented in USEPA (2006) were adjusted upward by the CPI to reflect values in 2018:

Species Group	Recreational Harvested Value (2018 $/fish)		
	Minimum	Most Probable	Maximum
Panfish	0.63	1.16	2.13

To convert these values to a weight basis to be consistent with the biological benefits calculation, each of these recreational values were divided by a range in weights per fish based on best professional judgement. The resulting average weights per fish used are as follows:

Recreationally-Harvested Species	Average Weight per Fish Harvested (lb/fish)		
	Minimum	Most Probable	Maximum
Channel catfish	2.0	3.0	4.0
Freshwater drum	0.8	2.9	5.0

The resulting minimum and maximum values per pound of fish were the lowest and highest values calculated whereas the most probable was assigned as the median value for all combinations of value per fish and average weight. The resulting recreational values for each Target Species are as follows:

Recreationally-Harvested Species	Recreational Harvested Value (2018 $/lb)		
	Minimum	Most Probable	Maximum
Channel catfish	0.16	0.39	1.06
Freshwater drum	0.13	0.43	2.84

These most probable values were used to provide the best estimates of equivalent loss while the maximum and minimum values were considered in the uncertainty analysis.

Non-Harvested Fish

Traditionally, the economic value of recreational fishing has been based on the number of fish harvested (i.e., caught and kept). Values of this type can be estimated based on fishing mortality rates, as discussed above. However, increasingly recreational fishermen have been releasing fish alive back to the water body rather than keeping them. Reasons for such releases are multifold. For example, fish might be released as a result of catch and/or size limits. Further, fish might not be kept because the fisherman might choose not to eat the fish. Finally, fishermen release fish for potentially altruistic reasons; to ensure future fishing opportunities for themselves and others. Whatever the reason, catch-and-release is becoming an increasing factor in recreational fishing and the result is that a released fish can live to be caught again (and even multiple times) whereas a harvested fish is caught only once.

Unfortunately, there is not a wealth of information on how recreational fishermen value a caught and released fish versus a caught and kept one. However, both target species are popular targets of those fishing for panfish. Hence, it is reasonable to assume that most fishermen fish for these two species for food instead of merely sport. Therefore, for the purposes of this study, it was assumed that a released individual was, on average worth only 50 percent of the value of a harvested fish with a range of 25 to 75 percent.

Estimates of the release rates were determined from a 2004 survey of recreational fishers in the Missouri River (MDOC 2011). Data obtained from this survey revealed that 0.97 channel catfish were released for each individual harvested. Similarly, this survey revealed 2.83 freshwater drum were released for each individual harvested. This pattern is consistent with the relatively popularity of channel catfish as food compared to that of freshwater drum.

Using this information, the value of the recreational catch that was released as estimated for the one recreationally fished Target Species as follows:

$$RRFB_S = RHFB_S \times RFHF_s \times RVHF_s$$

where:

$RRFB_S$ = Economic benefit ($) to recreational catch and release fishing for each Target Species (S);
$RHFB_S$ = Economic benefit ($) to recreational harvest fishing for each Target Species (S);
$RVHF_S$ = Relative value of each harvested fish to each released fish; and,
$RFHF_S$ = Number of released fish for each harvested fish for Target Species (S).

Total Recreational Benefit

The total economic benefit (RFB_s) associated with recreational fishing for each of the two recreationally harvested species is then the sum of the benefit associated with harvest of fish plus the benefit associated with catch and release; each described above:

$$RFB_S = RHFB_S + RRFB_S$$

Non-Use Benefits

As previously discussed, this category, also known as passive use values, includes all benefits above and beyond any accrued through use of the resource. Most commonly cited non-use benefits include bequest and existence values (EPRI 2017). USEPA (2014) acknowledges that these benefits can best be estimated using contingent valuation methods on a site-specific basis. However, they concluded that such studies are unlikely to be conducted for specific facilities and were clearly beyond the scope and budget of USEPA for development of the § 316(b) regulations.

In the benefits valuation for the § 316(b) Phase II rule (USEPA 2004), USEPA provided that, "In cases where an impingement mortality and entrainment characterization study does not identify substantial harm to a threatened or endangered species, to the sustainability of populations of important species of fish, shellfish, or wildlife, or to the maintenance of community structure and function in a facility's waterbody or watershed, monetization [of non-use benefits] is not necessary" [p. 41648]. However, they do require a qualitative discussion of these benefits if they are believed to exist. This issue is discussed in more detail in EPRI (2017).

No T&E species were collected in entrainment or impingement samples at the LEC during the course of the two study years. Further, the levels of entrainment and impingement at the LEC are low relative to the reproductive potential of each of the Target Species and unlikely to induce population-level effects for any of the species involved. Hence there is no evidence that its cooling water intake structure is causing “substantial harm” to T&E species or to aquatic populations and communities of the Missouri River from which cooling water is withdrawn. Therefore, consistent with USEPA (2004) and EPRI (2017), non-use values were deemed very small or non-existent and, therefore, not included in this economic valuation.

11.3.1.2 Estimated Total Annual Economic Benefits

The total annual economic benefits for the Target Species entrained or impinged is the sum of the annual economic benefits for all benefit categories described above. These Target Species, however, do not account for all fish entrained or impinged at the facilities included in this assessment. The following equation was used to account for the value of non-Target Species entrained or impinged at each facility:

$$Ben_{non-TS} = \left[\frac{1}{IF_{TS}} - 1\right] \times \sum_{TS=1}^{n} (CFB_S + RFB_S)$$

where:

Ben_{non-TS}	=	Economic value of non-Target Species;
n	=	Number of Target Species plus the Equivalent Predator; and,
IF_{TS}	=	The fraction of total annual entrainment or impingement loss accounted for by the n Target Species for each year and technology alternative

The total annual economic benefit (TAEB) for each technology alternative of <u>all</u> fish species entrained or impinged at the facility is then the sum of the benefits to the Target Species, the benefit to the Equivalent Predator, and the benefit to non-Target Species:

$$TAEB = \sum_{TS=1}^{n} (CFB_S + RFB_S) + BEN_{non-TS}$$

11.3.1.3 Annual Estimates

Across all alternatives, estimates of the annual economic benefits of reductions in entrainment loss ranged from approximately $700 to slightly more than $10,000 per year, depending on study year and alternative (Table 11-14). Estimates of annual economic benefits of reductions in impingement loss ranged from less than $3,000 to almost $5,000 per year across the alternatives and study years (Table 11-15). Finally, total annual benefits of reductions in entrainment and impingement combined ranged from just over $3,000 to just over $15,000 per year across the alternatives and study years (Table 11-16).

11.3.2 Lifetime Economic Benefits

11.3.2.1 Methods

In order to compare the benefits of any alternative to the costs of that alternative, economic benefits must be accumulated over the entire time these benefits are likely to accrue. In the case of cooling water intake alternatives selected to reduce entrainment, this would be the lifetime of the facility as it is currently operating. This accumulation must take into account the time value of money (i.e., money in the future has less value than money in the present) through a discounting the value of economic benefits in the future. NPV is a well-established technique to estimate the total value of economic benefits accrued over time. NPV of the lifetime benefits for each alternative was calculated from the TAEB as follows:

$$NPV = \sum_{t=1}^{T} \frac{TAEB}{(1+i)^t}$$

where:

NPV = Net Present Value of each alternative
T = Total number of years (t) of operation
i = Assumed interest rate.

In this study, both fine mesh traveling water screen alternatives were assumed to be installed at the LEC by 2026 with half of them being installed in 2025. Cooling towers would be installed beginning in 2026 with one quarter of them being installed in that year and an additional 25 percent being installed each subsequent year. Increases in the catch by commercial and recreational fishermen were then assumed to begin four years thereafter. It was assumed that these benefits would continue for an additional 30 years (through the year 2056). Two different interest rates (3 and 7 percent) were used as recommended in USEPA (2010).

11.3.2.2 Lifetime Estimates

Net present value of lifetime benefits of entrainment and impingement reductions over the remaining lifetime of the facility ranged from just over $18,000 to almost $208,000, depending on study year, alternative and assumed discount rate (3 vs 7 percent) (Table 11-17). Most of this benefit was as a result of reductions in entrainment loss of the forage base.

11.3.3 Other Potential Ecosystem Benefits

Some of the entrainment reduction alternatives considered in this assessment can have other benefits to the aquatic ecosystem beyond that accruing through reductions in entrainment and impingement. One benefit identified by USEPA in the § 316(b) Rule that must be addressed related to potential effects of thermal discharges. Section 122.21(r)(11) requires the following be included in the Benefits Valuation Study:

(vi) *Discussion, with quantification and monetization, where possible, of any benefits expected to result from any reductions in thermal discharges from entrainment technologies.*

Among the alternatives addressed in this Benefits Valuation Study, only closed cycle cooling has the potential to reduce thermal discharges. Hence, this alternative is the only one to potentially have any benefits from reductions in thermal discharges if selected as the entrainment BTA at the LEC.

Thermal discharges are independently regulated as a pollutant under the CWA which requires each facility to either meet existing water quality criteria for temperature or obtain a site-specific variance under § 316(a) of the CWA. By meeting existing water quality criteria for temperature a facility is protective of aquatic resources while a § 316(a) variance can only be granted if the site-specific thermal limits ensure the protection of balanced indigenous communities in the receiving water body. The LEC has been operating under a § 316(a) variance since 1977. Currently, the LEC is preparing an application for a new variance that will be submitted in 2019 as required by their NPDES permit. As any variance granted must insure the continued protection of a balaced indigenous community, any reductions in thermal discharge, such as though installation of cooling towers will not have any demonstrable benefits to the aquatic community in the vicinity of the LEC as the variance ensures that the community is already protected from the discharge of heat.

Table 11-14 Estimated annual economic value (2018$) by Target Species and technology alternative at the LEC from entrainment by study year.

Study Year = 2015/Flow Year = 2015			
Target Species	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	328	330	459
Freshwater drum	356	390	2,155
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[a]	216	272	1,076
Non-Target Species	1,657	1,825	6,794
Total	2,556	2,817	10,485
Study Year = 2016/Flow Year = 2016			
Target Species	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	83	83	102
Freshwater drum	166	190	1,484
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[a]	59	122	561
Non-Target Species	394	505	2,743
Total	702	900	4,890

[a] Equivalent predator set to channel catfish.

Table 11-15 Estimated annual economic value (2018$) by Target Species and technology alternative at the LEC from impingement by study year.

Study Year = 2005/Flow Year = 2015			
Target Species	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	355	355	436
Freshwater drum	1,580	1,580	3,063
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[a]	528	528	1,016
Non-Target Species	143	143	263
Total	2,607	2,607	4,777
Study Year = 2005/Flow Year = 2016			
Target Species	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	302	302	371
Freshwater drum	1,473	1,473	2,854
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[a]	480	480	924
Non-Target Species	131	131	241
Total	2,386	2,386	4,390

[a] Equivalent predator set to channel catfish.

Table 11-16 Estimated annual economic value (2018$) by Target Species and technology alternative at the LEC from entrainment and impingement combined by study year.

Study Year = 2015-2005/Flow Year = 2015			
Target Species	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
Channel catfish	683	685	896
Freshwater drum	1,937	1,970	5,218
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[a]	744	800	2,091
Non-Target Species	1,800	1,969	7,057
Total	5,163	5,424	15,262
Study Year = 2016-2005/Flow Year = 2016			
Target Species	**Fine Mesh Traveling Screens (2.0 mm)**	**Fine Mesh Traveling Screens (0.5 mm)**	**Closed Cycle Cooling**
Channel catfish	385	385	473
Freshwater drum	1,639	1,663	4,338
Gizzard shad	0	0	0
Minnows	0	0	0
Equivalent predator[a]	539	602	1,484
Non-Target Species	525	636	2,985
Total	3,087	3,286	9,280

[a] Equivalent predator set to channel catfish.

Table 11-17 Estimates of the net present value (2018$) of reductions in entrainment and impingement combined by Target Species, Alternative and Year at the LEC.

Entrainment				
Discount Rate	Flow Year	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
3 percent	2015	34,771	38,311	142,603
	2016	9,541	12,241	66,507
7 percent	2015	15,166	16,710	62,199
	2016	4,162	5,339	29,008
Impingement				
Discount Rate	Flow Year	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
3 percent	2015	35,454	35,454	64,976
	2016	32,450	32,450	59,712
7 percent	2015	15,464	15,464	28,340
	2016	14,154	14,154	26,044
Entrainment and Impingement Combined				
Discount Rate	Flow Year	Fine Mesh Traveling Screens (2.0 mm)	Fine Mesh Traveling Screens (0.5 mm)	Closed Cycle Cooling
3 percent	2015	70,225	73,765	207,579
	2016	41,991	44,691	126,219
7 percent	2015	30,630	32,174	90,539
	2016	18,315	19,493	55,053

11.4 UNCERTAINTY ANALYSIS

The results of any estimation process such as a benefits valuation study wherein the input parameters and model structure are difficult to measure precisely carry some level uncertainty. Uncertainty refers to the lack of knowledge about measures and components that go into each element of the Benefits Valuation Study. Although not explicitly required as the requirements of § 122.21(r)(11), USEPA's own guidance for conducting economic analyses (USEPA 2010) concludes that "Conveying uncertainty effectively and reporting critical assumptions and key unquantified effects to decision makers is critical at all points in the policy-making process" (p.11-1). Further, they recommend that in presenting the results of economic analysis, the reader, among other things, should be able to understand:

- "What the primary sources of uncertainty are in the analysis; and,
- How those sources of uncertainty affect the results." (p.11-1).

Finally, USEPA recommends “Estimates of costs, benefits and other economic impacts should be accompanied by indications of the most important sources of uncertainty embodied in the estimates, and, if possible, a quantitative assessment of their importance.” (p.11-9) and that “Ideally, an economic analysis would present results in the form of probability distributions that reflect the cumulative impact of all underlying sources of uncertainty. (p.11-9)”.

Addressing the recommendations of USEPA’s economic guidance can best be done through an Uncertainty Analysis. The purpose of the Uncertainty Analysis is to make transparent all the underlying sources of uncertainty in the calculation of economic value such that the appropriate regulatory authority can independently determine whether the results have sufficient precision and accuracy to meet regulatory needs and form sufficient basis for sound regulatory decisions. The purpose of this section is to evaluate the effects of uncertainty in key input parameters on the estimates of economic value in this assessment.

Uncertainty is not unique to an Economic Valuation Study under § 316(b). Some uncertainty exists in almost all predictions of future conditions based on past or existing information and this is especially true when dealing with environmental science and economic issues. In both environmental science and economics, inherent variability and limited understanding of underlying processes coupled with difficulty in making accurate measurements of underlying parameters makes consideration of uncertainty in these cases especially important. Uncertainty analysis is becoming an increasingly important part of cost-benefit assessments as they play a greater role in the environmental regulatory process.

Uncertainty arises in assessments such as a Benefits Valuation Study from three general sources: natural variation, uncertainty in model structure, and uncertainty in model parameters. Natural variation results from natural differences across elements within a population or in a population across time. For example, not all members of the United States population are expected to value increased recreational fishing opportunities to the same degree. Alternatively, wide year-to-year differences in entrainment and impingement densities at the same facility are common. These differences in abundance can result in large differences in the annual economic value. Both of these examples can yield uncertainty in the total economic value estimated under § 316(b).

Uncertainty related to model structure arises from the lack of knowledge as to what is the most appropriate form of the model to accurately describe the process being modeled. For example, the form of the relationship between the number of trips and travel cost in a simple travel cost model has been assumed to be linear, semi-logarithmic, or logarithmic by various analysts (Rosenberger and Loomis 2001). However, the most appropriate form is still a matter of debate. Likewise, an alternative that reduces total cooling water flow, such as closed cycle cooling, can result in reduced entrainment and impingement. Most commonly, an assumption of a linear relationship with cooling water volume is made. However, this assumption also remains an area of debate.

Finally, uncertainty in model parameters can result from difficulty in measurement or in inherent variability in the model parameter. This is likely to be the most frequently encountered source of uncertainty in economic valuation under § 316(b). Examples of this source of uncertainty include estimates of life stage-specific life history parameters for equivalent loss estimation and measurements of fishermen’s “willingness to pay” obtained from surveys.

In this section, three broad areas of uncertainty are addressed: parameters used to estimate direct and indirect use values, questions regarding the use and magnitude of non-use benefits, and the economic factors used to estimate the lifetime benefits, focusing primarily on uncertainty in model parameters. More general information on these sources of uncertainty relative to § 316(b) is provided in EPRI (2017).

As indicated by USEPA (2010), uncertainty can be addressed either quantitatively (e.g., sensitivity or Monte Carlo analysis) or qualitatively. The results of uncertainty analysis using each of these approaches for the LEC are discussed below.

11.4.1 Quantitative Analysis of Uncertainty

Sufficient information exists to conduct a technically sound Uncertainty Analysis quantitatively for many of the inputs used to estimate equivalent loss and resulting economic value. Key input parameters addressed quantitatively include:

- Commercial Price;
- Exploitation Rate;
- Fishing Mortality Rate;
- Fishing Vulnerability;
- Fraction Commercial;
- Fraction Released;
- Natural Mortality Rate;
- Fine-Mesh Screen Survival;
- Production Surplus;
- Recreational Price;
- Relative Value;
- Trophic Conversion; and,
- Weight

Two other key input factors, inter-annual variability in the entrainment and impingement rates and in cooling water flows, were not explicitly addressed in this uncertainty analysis but, instead, were address in a semi-quantitative manner in Section 11.4.1.

Uncertainty for this assessment was addressed by two means. First, a sensitivity analysis was conducted on individual input parameters. Second, a Monte Carlo analysis was conducted to determine the likely overall uncertainty in the estimates of annual economic value resulting from the current levels of uncertainty. The results of each of these analyses are provided below.

11.4.1.1 Sensitivity Analysis

A sensitivity analysis was conducted individually on each of the twelve input parameters listed above. Multiple calculations of annual benefits were made using the extreme values (i.e., maximum and minimum) for each parameter while holding all other parameters constant at their most probable values. The purpose of this sensitivity analysis was to determine the parameters for which the current levels of uncertainty had the greatest effect on the estimates of annual economic benefit.

The results from the 0.5-mm fine-mesh wedge wire screen alternative for entrainment as an example revealed the recreational price per fish yielded the greatest range in estimates of annual economic benefits (-243 to +34 percent) while uncertainty in the natural mortality rate was the next most important (Figure 11-1). Uncertainty in these two parameters was clearly the most important factor in determining the total uncertainty in the estimate of annual economic benefits at the LEC. Uncertainty in the remaining ten input parameters individually had much smaller effects on estimates of annual economic value. Sensitivity results for the other alternatives and study years were similar.

11.4.1.2 Monte Carlo Analysis

Monte Carlo analysis was used to assess the overall uncertainty in the estimates of total annual economic value based on the current levels of uncertainty in each of the twelve input parameters. For each of these parameters, random values were selected from a triangular distribution[2] wherein the maximum and minimum values for the distribution were set to the maximum and minimum values for each parameter described earlier and the mode of the distribution was set to the mid-point used as the best estimate for each parameter. Values for each parameter were randomly selected separately for each species and life stage and the Monte Carlo analysis was run using 1,000 iterations to define the resulting frequency distribution in annual estimates of economic benefit.

The results from the 0.5-mm fine-mesh traveling water screen alternative revealed the frequency distribution of the resulting annual estimates from the Monte Carlo analysis appeared generally symmetrical and centered about 0 (Figure 11-2). It appears highly unlikely that the true annual economic benefit was more than five times the most probable estimate reported in Section 11.3. Monte Carlo results for the other technology alternatives and study years were very similar.

11.4.2 Qualitative Discussion Of Uncertainty

Uncertainty in a variety of other assessment inputs and assumptions could not be assessed quantitatively; hence, these factors were addressed qualitatively. In this qualitative assessment, the nature of the uncertainty is discussed along with an assessment of the likely magnitude, and, if possible, direction of the effect that uncertainty might have in estimates of economic value. Each of these factors are grouped into one of three categories and discussed below.

11.4.2.1 Factors That Lead To Overestimates Of Economic Value

Uncertainty in these factors tends to result in estimates of economic value that are higher than the true value.

Entrainment Survival

In this study, each of the life stages of each Target Species were conservatively assumed to die as a result of being entrained through the cooling water system at the LEC. However, there is ample evidence that many of the entrainable life stages of many species can and do successfully survive passage through the cooling water systems at many facilities and are returned to the source waterbody unharmed provided discharge temperatures remain low (e.g., < 90°F) (EPRI 2009). While there is not a lot of information currently available on the entrainment survival of

[2] The triangular distribution is one of a large number of possible distributions that could be used for each of the input parameters. Unfortunately, sufficient information to accurately describe the underlying frequency distributions for each input parameter does not exist. This commonly used distribution is flexible to meet a wide variety of situations and is defined by set maximum, minimum and most probable values. As used in this analysis, the triangular distribution is symmetrical like the normal distribution but constrained within set maximum and minimum values.

freshwater species, several of the Target Species for the LEC which contributed to most of the biological benefits of each alternative, such as freshwater drum and channel catfish, can be considered relatively hardy. It is reasonable to expect that many of the eggs and larvae of these hardy species would survive entrainment at the LEC at rates up to or even exceeding 50 percent. Hence, the conservative assumption that no organisms survive entrainment at the LEC could lead to a substantial overestimate of the biological benefits of each intake alternative.

Density dependence

While there is general agreement as to the importance of density to population processes, the magnitude of effects of organism density on growth, reproductive, and mortality rates, especially when it comes to assessment of entrainment effects, has been an area of controversy for many years. In valuation, it was assumed that the life table inputs (i.e., mortality and growth rates) remain constant and equal to those developed using available scientific information together with BPJ. Since entrainment results in the loss of organisms, it is possible that such processes could lead to reductions in densities sufficient to yield increases in population survival and growth rates. To the extent that such processes occur, estimates of economic value and the benefits of any intake alternative will be overestimated. The magnitude of such overestimation will depend on a variety of factors, including the magnitude of other sources of mortality as well as the life history strategies of those species involved.

Selection of equivalent predator

In this assessment, a single equivalent predator, channel catfish, was used. This means that it was assumed that all biomass production that the organisms entrained would have produced would have been consumed only by this species. However, in reality, biomass produced by organisms not entrained could have been consumed by a wide variety of predators including fish, larger invertebrates, and birds as well as by lower trophic levels through decay.

Channel catfish is a very popular target of recreational fishermen in the area and, as a result, is highly valued as measured in willingness-to-pay estimates. Hence, it is likely that in reality at least a portion of the production foregone estimated in this study would be consumed by predators less valued by fishermen. To the extent that this occurs, the economic value and benefits of any intake alternative as estimated in this study will be higher than actually exists.

Fish Consumption Advisory

The values per fish caught by recreational fishermen were based on studies conducted throughout the inland waters of the U.S. (USEPA 2006) and most likely focused on waters where consumption of fish was common. However, in the lower Missouri River there is currently an advisory recommending only limited consumption of fish from the River owing to contamination by PCSs, chlordane and mercury (MDHSS 2019). This fish consumption advisory could reduce the desireability of recreational fishermen to fish in this area, and hence, reduce there value. To the extent that this occurs, the benefits of any fish protection technology would be overestimated.

Changes in the fish community

Estimates of the economic benefits of each alternative through reductions in impingement were based on impingement monitoring data collected in 2005 and 2006. Since that time, the abundance of Asian carps in the area near LEC has significantly increased resulting in a fish community that is likely different from that when the impingement data were collected. If the increased abundance of Asian carps has resulted in the decreased abundance and, hence, reduced impingement rates of native species at the LEC then the benefits through reductions in impingement would be overestimated.

11.4.2.2 Factors That Lead To Underestimates Of Economic Value

Uncertainty in these factors tends to result in estimates of economic value that are lower than the true value.

Collection efficiency

In this assessment, we assume that the estimates of entrainment and impingement for the Target Species are accurate. However, there are a variety of factors that can lead to underestimates of actual entrainment or impingement. These factors are typically site-specific and can vary with species and characteristics of the biological sampling design. Collectively the degree to which measures of entrainment or impingement accurately reflect true entrainment or impingement is known as collection efficiency. Collection efficiency in entrainment and impingement studies are discussed in detail in EPRI (2004b and 2014). To the extent that reduced collection efficiency leads to estimates of entrainment or impingement that are biased low, an underestimate of true economic value and benefit of any intake alternative will result.

11.4.2.3 Factors That Could Yield Either Overestimates Or Underestimates Of Economic Value

Uncertainty in the following factor tends to result in estimates of economic value that are either higher or lower than the true value.

Inter-annual Variability in Entrainment and Impingement Densities

Total entrainment and impingement at any single cooling water intake structure is rarely consistent from one year to the next. In fact, wide swings in entrainment and impingement at any single facility are the norm rather than the exception (EPRI 2004b and 2014). Such wide swings in abundance are most common where species with especially high reproductive potential dominate entrainment and impingement collections such as those that dominate collections at the LEC. These species tend to naturally exhibit large differences in early life stage abundance from one year to the next as a result of highly variable environmental conditions.

At the LEC, total annual entrainment under baseline operations was slightly higher in 2015 than in 2016 (Table 11-2 and 11-3). Reasons for these differences are unknown but are most likely a product of natural yearly variation in reproductive success. In addition, there were differences in species and life stage composition of the Target Species entrained between the two study years. While minnow PYSL were dominant in both years, gizzard shad PYSL were the second most abundant life stage in 2015. However, in 2016 gizzard shad were replaced by freshwater drum, largely YSL. As a result estimates of economic benefits of each alternative in 2015 were two to four times higher than that estimated for 2016. There was only a single year of impingement data. Therefore, the effects of year-to-year changes in impingement rates cannot be addressed for the LEC. However, given the magnitude of differences in annual economic benefits from one year to the next in entrainment alone, it is likely that this single factor will dominate uncertainty in estimates of economic benefits of alternatives at many, if not most, facilities like the LEC. Unfortunately, without long-term entrainment and impingement data, potentially over decades, it will be difficult to assess the the full magniture of uncertainty of both economic benefits of alternative installation attributable to this factor at any single facility.

Inter-annual Variability in Water Withdrawals

Year to year differences in the operation of any individual facility can affect patterns in water withdrawals and, hence, entrainment and impingement losses. However, some facilities, like the LEC, run in a fairly consistent manner from one year to the next. Hence, data exhibit relatively small differences in annual water withdrawals. Hence, differences in the water withdrawal rates from one year to the next does not appear to be a significant contributor to the uncertainty in estimates of economic benefits for any of the alternatives considered in this study.

11.4.3 Uncertainty Summary

Quantitative analysis of the effects of uncertainty associated with selected input parameters revealed little chance of the actual economic benefits associated with any of the alternatives was more than twice that reported in Section 11.3. This uncertainty was principally driven by uncertainty in the estimates of the value per pound assigned to recreational catch and natural mortality rate. Other factors which appear to substantially contribute to uncertainty include the year-to-year variability in entrainment densities. However given the relatively low estimates of economic benefits for each alternative, such uncertainty is unlikely to have any consequence to the entrainment BTA selection process.

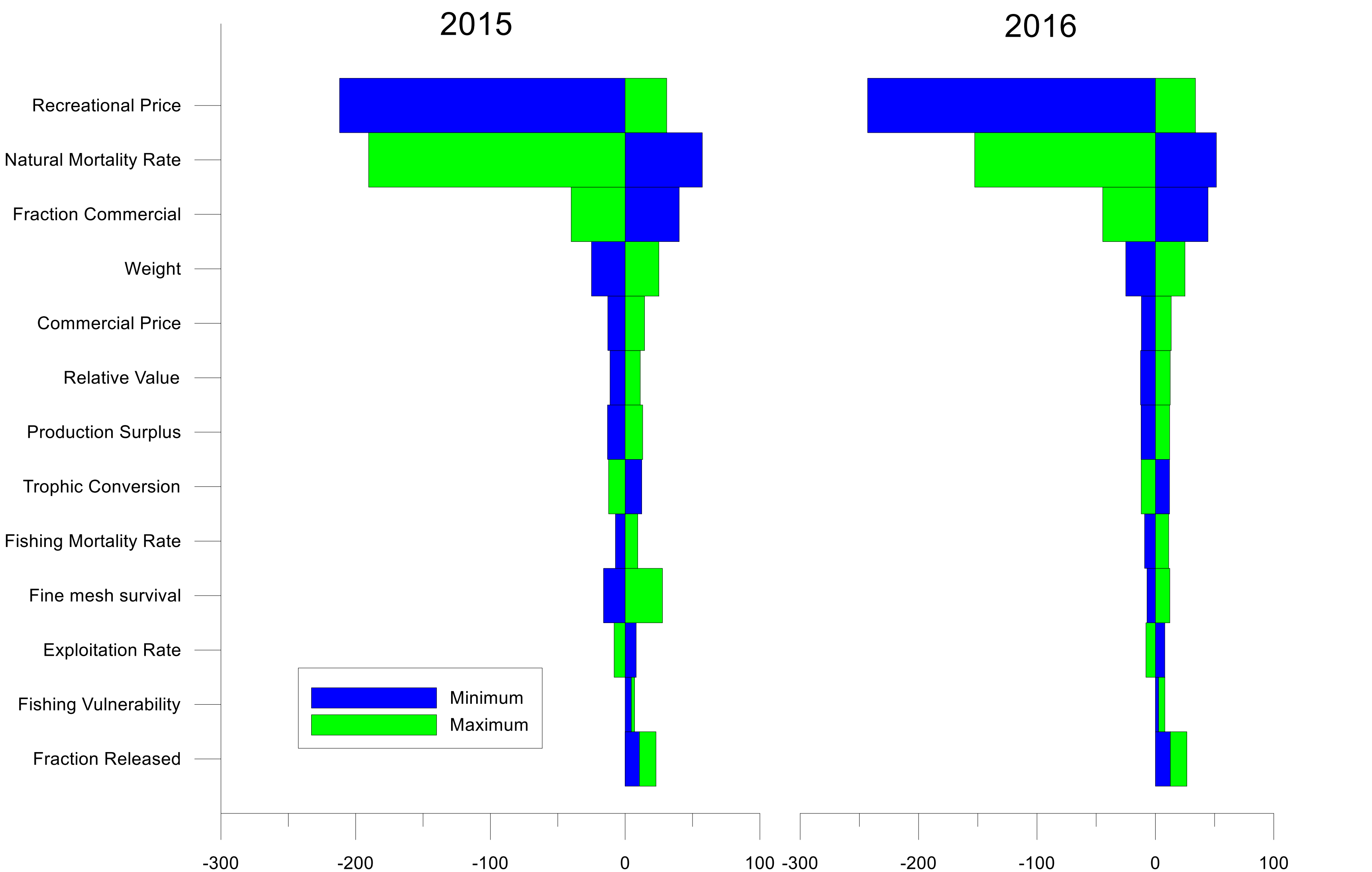

Figure 11-1 Estimates of the range of effects of uncertainty in each input parameter on estimates of annual economic benefit from entrainment and impingement reductions from 0.5-mm fine mesh screens at the LEC entrainment and flow data from 2015 – 2016 and impingement from 2005.

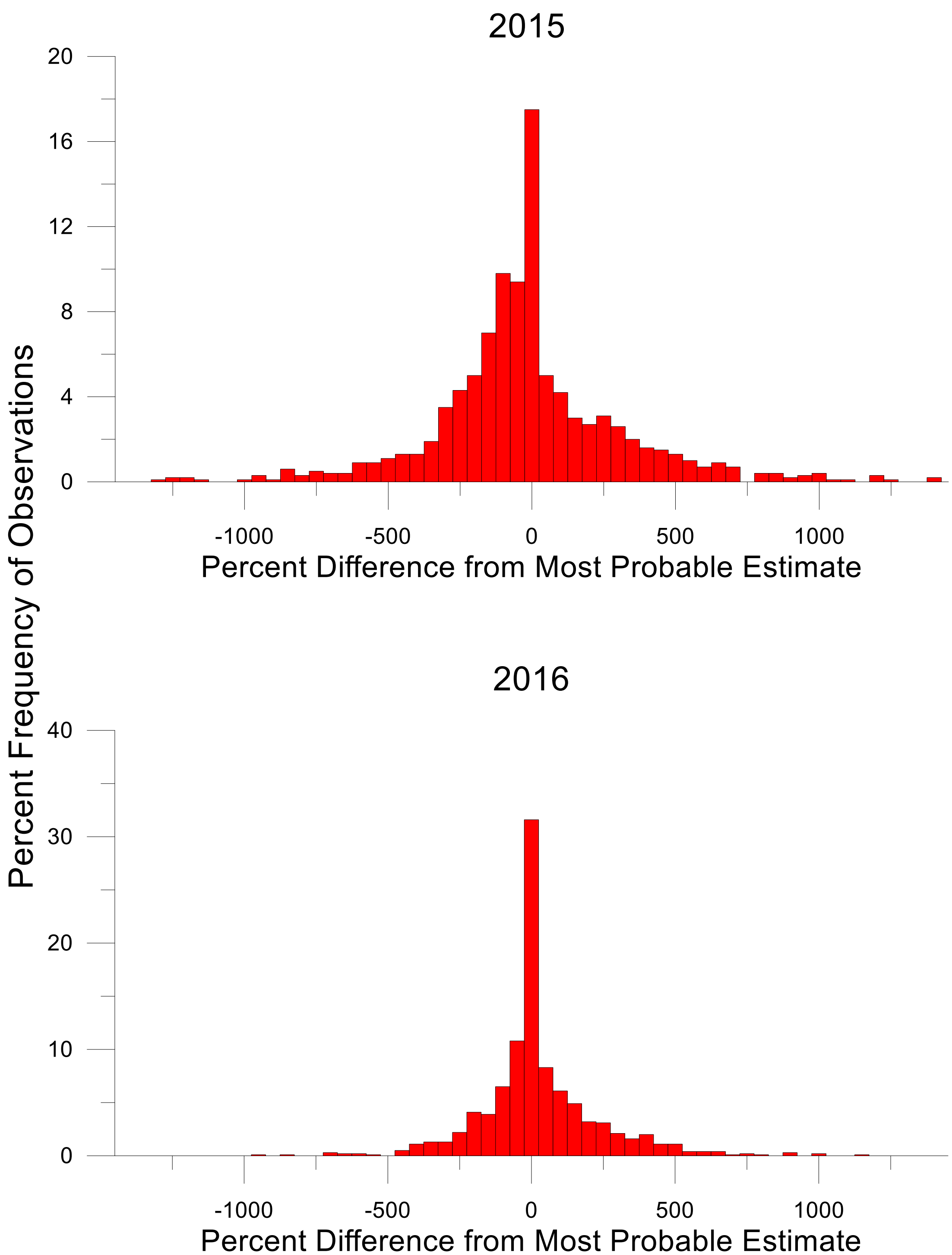

Figure 11-2 Results of Monte Carlo analysis of uncertainty in all input parameters on estimates of annual economic benefits from entrainment and impingement reductions from 0.5-mm wedge wire screens at the LEC entrainment and flow data from 2015 – 2016 and impingement

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